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Location:	**HRI, East Malling**
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DEVELOPMENT OF EQUIPMENT TO MEET THE ENVIRONMENTAL NEEDS OF LEAFY CUTTINGS DURING ROOTING

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CONTENTS

RELEVANCE TO NUSERYMEN AND PRACTICAL APPLICATION

Application

The majority of ornamental shrubs are raised from leafy cuttings, which form the bulk of the estimated 200 million cuttings propagated each year in the UK.

The cutting, when isolated from the stockplant, is prone to stress, wilting and possibly death, and as the environmental needs of cuttings are better understood (Harrison-Murray *et al.*, 1993), it becomes clear that few commercial propagation units are ideal in this respect (Thompson *et al.*, 1993).

Central to creating a suitable propagation environment is the equipment used to achieve humid and/or wet conditions, and the way in which the frequency of misting or fogging is regulated in an attempt to meet the cuttings' need for environmental support, which fluctuates with changing weather.

The work reported here produced a high output single-source fogger with fan-assisted distribution, which was safer and more reliable than existing equipment of a similar type. An environmental sensor was developed also which, by responding to the combined effects of all the factors which affect water loss from leaves, was capable of controlling fog and mist in a way that matched the needs of cuttings more closely than previous controllers. One benefit is that lower shade levels can be used without danger of severe stress on the brightest days. Trials with this new "evapostat" control show it to respond rapidly and sensitively to changing weather conditions, resulting in excellent rooting of a wide range of cuttings.

Summary

This work sought to improve opportunities for creating the optimum environmental conditions for the propagation of leafy cuttings by:-

1. Understanding the principles governing the use of air circulation fans to distribute fog, with a view to more even wetting of cuttings.

2. Producing a prototype fan-assisted fogger offering improved safety and reliability compared to the imported equipment which, in greatly modified form, is used for research at HRI East Malling.

3. Developing a rapid-response sensor of potential transpiration capable of monitoring and controlling propagation environments in a way that accurately reflects the needs of cuttings, so that stress can be avoided without recourse to excessive shade. "Potential transpiration" is a measure of how rapidly cuttings could be losing water under prevailing conditions.

An "HDC fogger" was developed as a satisfactory and safe alternative to the centrifugal Agritech fogger currently used to propagate a range of very difficult subjects at East Malling. However, the characteristic decrease in water deposition with increasing distance from the machine was **not** prevented by creating finer fog droplets. The explanation was found to be that the air turbulence induced by an axial fan strongly promoted deposition of even very fine droplets. Such turbulence cannot be avoided, but there are opportunities to exploit the gentle and predictable wetness gradient for different types of cuttings and for different purposes. The same does not apply to distributed

nozzle systems, where the often very steep gradients around each nozzle are too local to offer any such management opportunities. Nurserymen considering a fogging system need to consider these alternatives carefully.

A significant contribution to the operation of fog and mist systems was made by the development of a new type of sensor which can be used to control, or simply to monitor, the propagation environment in a way that is more relevant to leafy cuttings than any existing sensor. The improvement results from the fact that the sensor is sensitive to **all** the factors that influence water loss from cuttings (i.e. principally humidity, radiation and wetting). It will, for example, call for a rapid increase in fog or mist output during a sunny period, and then reduce output once leaves are thoroughly wet, while suppressing output completely under cool cloudy conditions unless ventilation is allowing the humidity to fall too low.

A commercial manufacturer of the new "evapometric" sensor, or of the complete "evapostat" control system, is being sought.

EXPERIMENTAL SECTION

Introduction

The environmental needs of leafy cuttings during propagation are being increasingly understood (Harrison-Murray *et al.*, 1993), alongside evidence of very variable and often sub-optimal conditions on commercial nurseries (Thompson *et al.*, 1993). This report describes progress made in developing fogging equipment capable of efficient humidification, together with sufficient output of water to keep leaves permanently wet, so as to enable cuttings to receive favourably high light without becoming stressed. Also described is the development of an improved monitoring and control system to regulate the output of fog or mist to meet the varying demands created by changing weather conditions,

Background

The Agritech fogger used in HDC experiments at East Malling is a high output centrifugal machine with the additional benefits of an inbuilt fan and an oscillating mechanism to aid water distribution. Its output of 135 litres per hour is enough to allow the house to be force-ventilated because the drier incoming air is thoroughly humidified before it reaches the cuttings. This means that it is possible to maintain virtually 100% humidity in the 19.5 x 7.0 m polythene tunnel while preventing temperature exceeding about 30°C. However, there are some major drawbacks to this American-produced machine, including its limited availability in the UK and the substantial modifications we have needed to make to bring it to a reasonable level of reliability and safety. For these reasons it cannot be recommended for UK nurserymen. The gradient of wetting that it produces, as the large droplets fall out relatively quickly while the finer ones are carried for a greater distance, is also considered undesirable by some nurserymen.

The first aim of this project was to investigate alternative ways of producing a high fog output from a single point, with fan-assisted distribution, so as to overcome the drawbacks of the Agritech machine without sacrificing its basic virtues.

Our fogger was designed to provide an experimental rig with which to identify and nozzle systems, where the often very steep gradients around each nozzle are too local to offer any such management opportunities. Nurserymen considering a fogging system need to consider these alternatives carefully.

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The first aim of this project was to investigate alternative ways of producing a high fog output from a single point, with fan-assisted distribution, so as to overcome the drawbacks of the Agritech machine without sacrificing its basic virtues.

Our fogger was designed to provide an experimental rig with which to identify and optimise important design characteristics (e.g. total output, droplet size distribution and location of water outlets in relation to airflow), and to incorporate features of safety, reliability, fog distribution and component availability that would make it commercially attractive.

At least as important as the means of misting or fogging is the method of controlling output. While the purpose of fog or mist is to prevent water stress by restricting the cuttings' transpiration none of the existing controllers respond to **all** of the environmental factors that affect transpiration. The most important of these for cuttings are radiation (i.e. essentially light), humidity and wetting. Even computerised systems are limited by the nature and quality of the sensors used to gather environmental data. Humidity is difficult to measure under wet conditions, and there is no sensor to determine the amount of water being deposited (although it is possible to sense whether cuttings are wet or dry). The second aim of the work therefore, was, to develop a control sensor which would regulate fog or mist according to the evaporative demand imposed on the cuttings by their environment. MAFF-funded work had already shown that such a sensor was possible in principle (Harrison-Murray, 1991), but the concept needed to be translated into practice.

Because negotiations with potential manufacturers are still proceeding, specific details of the sensor itself cannot be published. However, we can give a broad outline of the practical considerations relating to its use, including maintenance, interfacing with fog or mist equipment and sensitivity to location. We also present results that demonstrate the differences in the behaviour of the new sensor (described as an evapometric sensor because it measures evaporation) from that of a conventional humidity sensor, and report on our experience with it in controlling various foggers as well as closed and open mist systems. When combined with a suitable control unit to interface it to fog or mist, it is described as an "evapostat", by analogy with terms such as "humidistat" and "thermostat". Whilst this report relates only to its use as a **control** sensor it can also be used to **monitor** propagation environments. As such, it promises to be a valuable new tool for the **objective assessment** and management of propagation conditions in relation to **recommendations** for particular subjects, and it could also provide the basis for an alarm system to alert nurserymen to malfunction or breakdown of their mist or fog systems.

Fog terminology

The variation in fog droplet size is often referred to in terms of "wet", i.e. large droplet fog, and "dry", i.e. small droplet fog. The distinction is not clear cut and there is no simple means of measuring droplet sizes directly in order to make it a more objective description. Indeed, the concept of "dry" fog is something of a misnomer because even the finest droplets will deposit on surfaces to some extent (including those in natural fog) and, in **dense** "dry" fog, fine droplets collide, coalesce, and thus create larger droplets which settle more quickly. Fortunately, in the propagation context, it has been shown that the resulting wetting is an important component of a successful propagation environment. The term "dry" fog is retained as convenient shorthand for relatively fine droplet fog that is very visible and stays in suspension in still air for many minutes.

Materials and methods

The HDC fogger

The experimental machine (Plate 1) consists of a 43 cm diameter air-circulation fan, operating at 950 rpm and 4500 m^3/h. Mounted in front of the fan are four Sonicore fog nozzles, each with its own pressure regulators and valves. Both the quantity and quality of the fog produced by each nozzle can be adjusted independently. Increasing air pressure and/or reducing water pressure settings results in finer droplets. Such fine droplets theoretically have the advantage that they fall more slowly than larger drops and therefore tend to remain in suspension for longer. They also present a larger surface area in relation to their volume than larger drops and so humidify the air between the droplets more efficiently. However, such fine droplets can only be produced at the expense of a reduction in the quantity of water atomised so that it is useful to be able to set other nozzles on the machine to provide a higher output of relatively coarse droplets. Thus the fog can be "wet", "dry", or a combination of both. A water flow gauge provides a means of monitoring the output of either individual nozzles or the entire machine. For very high outputs the larger 086 nozzle is substituted for the normal 052 type (referred to as 'medium' and 'small' respectively below). The position of the nozzles relative to the air flow is also adjustable.

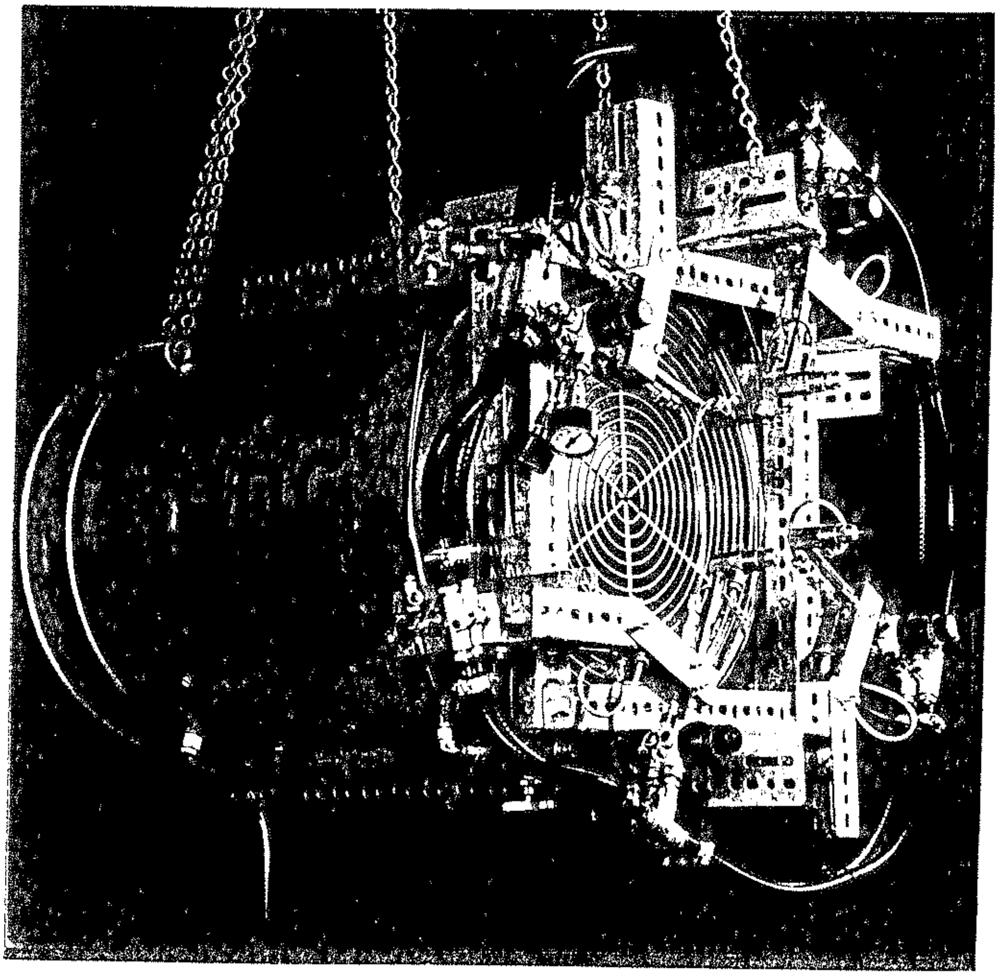

Plate 1. The HDC fogger : a test rig for optimising design parameters for fan-assisted foggers.

The test machine was positioned in the corner of a 10.5 x 7 m section of polytunnel, at a height of 1.5 m, and orientated so as to achieve an air flow that circulated around the compartment. Measurements were also made with a single fog nozzle mounted in the opposite corner of the house to the fan, where the air flow was much less turbulent. The performance of the Agritech fogger was measured in a 13.5 x 7 m tunnel with a water flow rate of 135 *l*/h and an air flow of 6790 m^3/h, with and without the benefit of a mechanism to oscillate the machine through a 130° arc.

Wetting patterns were measured by placing an array of 9 cm diameter dishes around the propagation house at cutting height. Dish locations were chosen to give both a representative measure of the average rate of water deposition (referred to as "fall out") and to provide a detailed picture of any wetting gradients. The fogging equipment was run continuously and the water deposited into the dishes over a given time was weighed to the nearest milligram. Results are expressed in millimetres of water deposited per day, by analogy with rainfall. The dishes were transparent, as were the stands on which they were placed, to minimise radiation-driven evaporation of the deposited water. Rates of fall-out were plotted against distance from the fog source, measured along the observed circulatory air flow around the polytunnel. Thus, in Figures 1 to 6, the mid-point on the horizontal axis represents the back of the house, where the air flow turned round to return towards the source of the fog (8 m from the HDC fogger, 11 m from the Agritech).

The evapometric sensor

The new sensor produces an electrical signal, the strength of which varies in line with potential transpiration. In its present form, the signal from our sensor is similar to that from a Nobel humidity sensor (Type HWA, from Clare Instruments, Woods Way, Goring, Worthing, BN12 4QY) so that the straightforward way to interface it to fog or mist is to use the humidity control unit (Type LHA) available from the same company. This unit incorporates a meter showing the sensor reading and can provide a link to a computer, integrator, or chart recorder for monitoring and/or alarm purposes. The sensor could be modified to provide a different type of electrical signal with possible benefits in terms of the cost of interfacing equipment. In the interests of protecting the HDC investment in this invention, further details of the sensor cannot be published at present while we are seeking a manufacturer.

Meaningful experiments to quantify effectively the advantage of the new sensor in terms of rooting cuttings would be very expensive and have not been attempted. In this context the "results" section is instead largely a summary of our experience in using the sensor in a number of different propagation systems, together with tests under controlled conditions to investigate how the response of an evapostat (i.e. a control system based on the evapometric sensor) compared with that of a conventional humidistat for fog control. By delaying this report beyond the end of the contract we have been able to incorporate this experience into our conclusions.

Rooting trials

Two rooting trials were carried out as follows, using the HDC fogger controlled by the new sensor:

Trial 1

Fogger set-up: 3 medium nozzles using air at 30 psi + 1 small nozzle using air at 65 psi, and with a total water flow of 85 litres/hour.

Propagation date 7th August; duration 4 weeks.

Species	Cutting Type
Ceanothus impressus	Apical
Cotinus coggygria 'Royal Purple'	Apical
Cornus alba 'Spaethii' LA79	Apical
Garrya elliptica 'James Roof'	Apical
Wisteria sinensis	Non-apical, 2 leaf

Trial 2

Fogger set-up: 1 medium nozzle using air at 30 psi + 1 small nozzle using air at 65 psi, and with a total water flow of 35 litres/hour.

Propagation date 19th September; duration 6 weeks

Species	Cutting Type
Aristolochia macrophylla	Mixed
Ceanothus impressus	Apical
Cryptomeria japonica 'Elegans Compacta'	Apical

All cuttings received a 5 second quick-dip treatment with 1250 ppm IBA (i.e. 1.25 g/*l* of indolyl butyric acid) in equal parts by volume of acetone and water. The compost was 1:1 peat:pine bark (Irish medium peat, and Cambark fine grade) with 1 kg/m^3 Ficote 140, 16:10:10 controlled release fertiliser added in the second trial. In both trials, cuttings were generally rather larger (up to about 20 cm tall) than is normal in the industry. Such cuttings tend to be more susceptible to stress but, provided the environment is appropriate to prevent such stress, they can have a higher rooting potential and produce a larger liner. Cuttings were placed at 3, 6 and 15 m from the fog source, measured as for the fall-out data (see above). The difference in wetting at these locations is shown in Figure 6.

A third trial examined the benefits of evapostat control of **mist** for propagation of *Acer palmatum* 'Aureum', a subject which requires wet and humid conditions to achieve good rooting, but whose leaves are prone to deteriorate under prolonged heavy wetting. The comparison was based on two identical polythene-enclosed mist beds. Two locations in our ventilated wet fog tunnel (timer-controlled Agritech fogger) were also included.

Results

HDC fogger: factors effecting uniformity of wetting

The air circulation fan improved the distribution of wetting but did not eliminate the wet zone close to the fogger. Irrespective of whether the fog nozzles were adjusted to "dry" or "wet" settings, a marked gradient of wetting remained even with the fan on (the broken line in Figs. 1 and 2). However, **beyond about 5 m from the fogger**, a very clear benefit of the drier setting was evident, with more or less uniform wetting being observed whether the fan was running or not (Fig. 1). In striking contrast, if the nozzles were set to generate "wet" fog, the circulation fan was essential to get much wetting at all beyond 8 m (i.e. on the return leg of the air circulation path) and, even then, wetting continued to decline, at about 10% per metre, over the remainder of the circulation path (Fig. 2). By comparison, the Agritech created a much more severe wet spot just 1 m from the machine (Fig. 3, dashed line), but was otherwise similar to the HDC fogger on "wet" settings. The benefit of an oscillator mechanism was clear (Fig. 3, solid line).

Without the circulation fan, the location of the wettest spot from the HDC fogger depended on the settings of the nozzles. It was immediately in front of the fogger when nozzles were set "dry", but was 4 m from the fogger when they were set "wet" (the solid lines in Figs 1 and 2). This reflected the shape of the spray plume; when set "dry" most of the fog-laden air emerged at right angles to the horizontally mounted nozzle and, impinging on the ground, many of the water drops were deposited as the air stream was forced to turn abruptly. When set "wet" the plume was elongated in the axis of the nozzle so that even the large drops were carried some distance from the fogger before dropping out of the plume onto the ground.

With the fan on, the location of the wettest spot was no longer sensitive to the type of fog being generated, and two wet spots were observed, one at 1 m and another at 4 m from the fogger. The second peak seemed to correspond to the point at which the blast of air emerging from the front of the fan, as a turbulent, spiralling, cone-shaped plume, first impinged on the ground. This suggested that fan-induced turbulence might be negating much of the potential benefit of creating very fine droplets (i.e. "dry" fog). To test this hypothesis, an additional experiment was conducted, in which "dry" fog was injected into the circulating air stream well away from the fan, where there was relatively little turbulence. To minimise turbulence created by the air flow from the nozzle itself, it was mounted in such a way that the air stream did not impinge directly on the ground or other surface. Figure 4 shows that, with the fan running (using the HDC fogger, with all nozzles turned off, as a fan), very uniform wetting was achieved for the first 6 m away from the nozzle, but that there was then a massive peak of wetting associated with the passage of fog-laden air through the fan. Without air circulation, wetting decreased progressively to the back of the tunnel, 8 m away from the nozzle, consistent with the idea that, as the concentration of "dry" fog rises, the droplets become increasingly likely to coalesce to form larger droplets which descend more rapidly.

When "wet" fog was generated remote from the fan, the air movement was not sufficient to carry much of it more than 3 m so that there was relatively little in the air by the time it passed through the fan and consequently only a relatively minor wetting peak formed in front of it (Fig. 5).

HDC fogger: rooting trials

Table 1 shows that under the control of the new evapometric sensor, the HDC fogger was capable of creating an environment which enabled cuttings of various species to root successfully, comparing favourably with results of other trials using the Agritech machine.

Figure 6 shows the location of the cuttings in relation to the distribution of wetting.

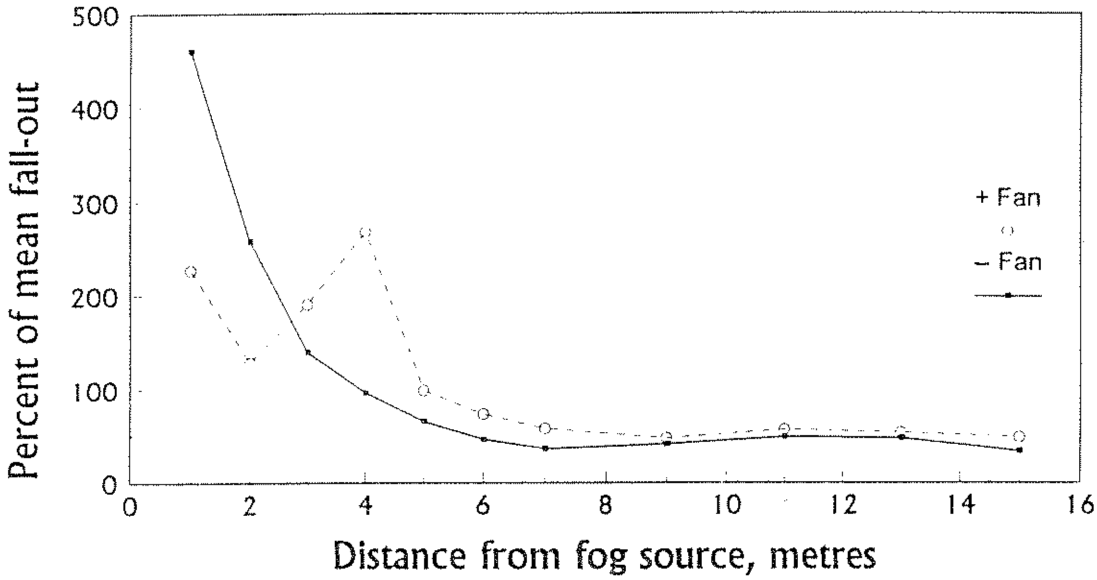

Figure 1. Fog fall-out from the HDC fogger with and without the circulation fan, when set to produce "dry" fog (3 small nozzles, 12 *l*/h total water flow, using air at 60 psi). Mean fall-out was 4.3 mm/day with fan, and 5.4 mm/day without.

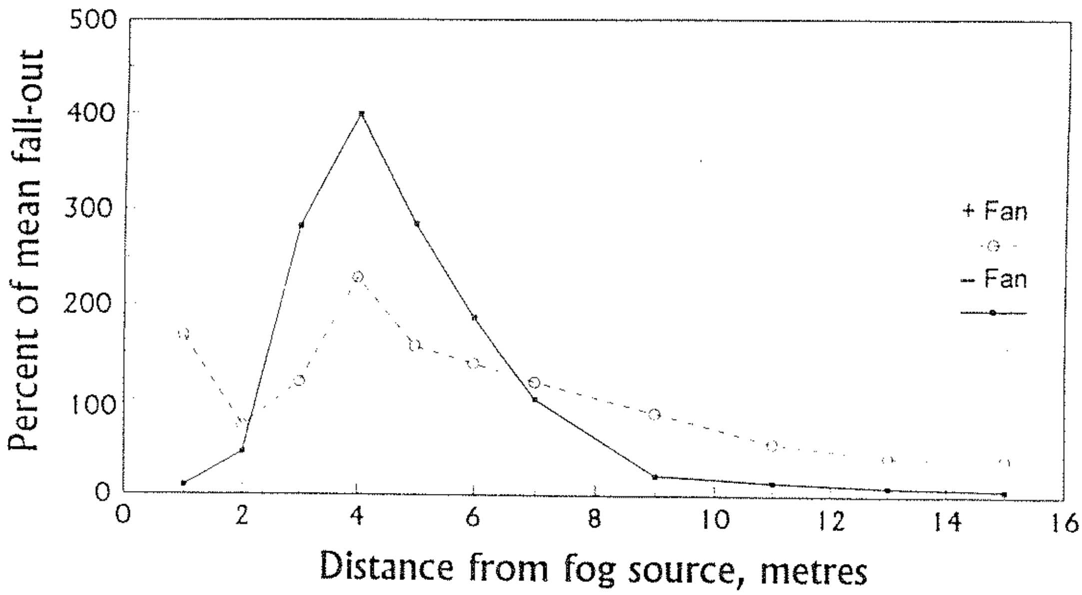

Figure 2. Fog fall-out from the HDC fogger with and without the circulation fan, when set to produce "wet" fog (4 medium nozzles, 86 *l*/h total water flow, using air at 60 psi). Mean fall-out was 25.3 mm/day with fan, and 50.0 mm/day without.

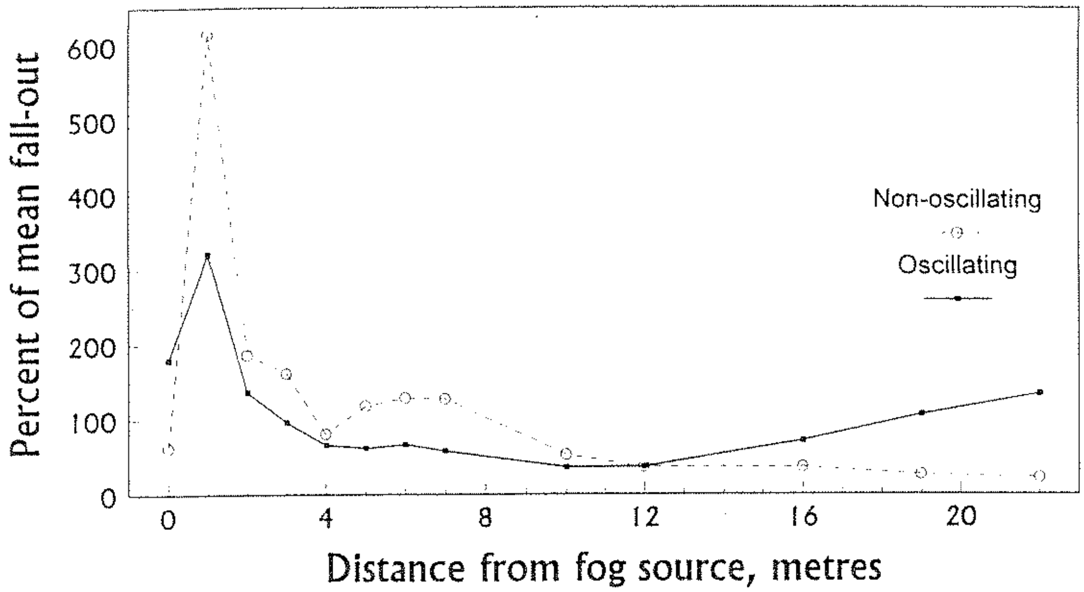

Figure 3. Fog fall-out distribution from the Agritech fogger with and without a mechanism to oscillate the fogger through 130° rotation. Mean fall-out was 20.0 mm/day with oscillation, and 24.5 mm/day without.

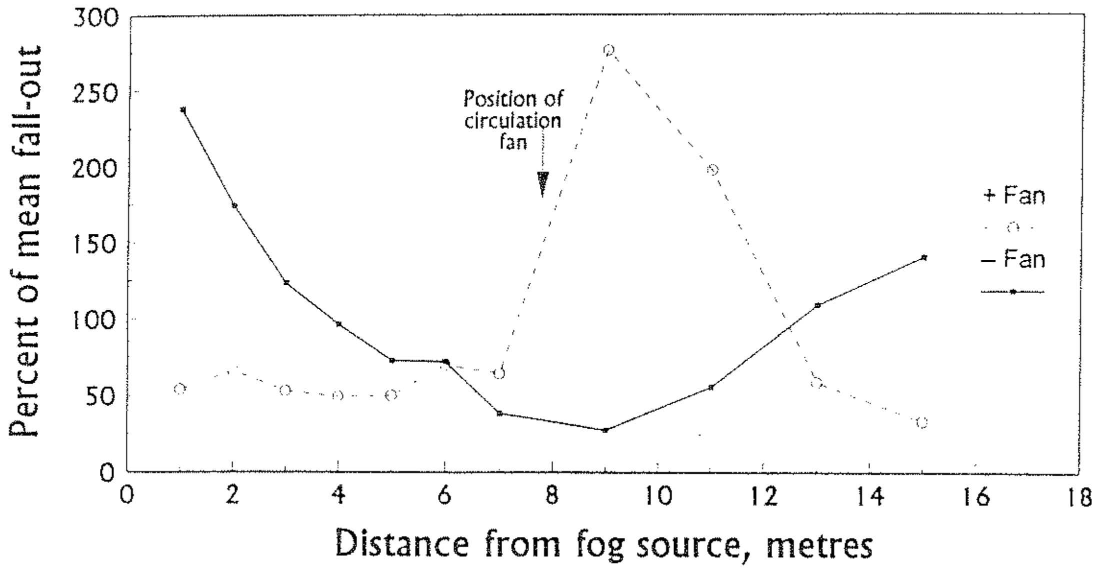

Figure 4. Fog fall-out from a single, vertical nozzle, set to produce "dry" fog (4 l/h water flow from a small nozzle, using air 60 at psi), with and without air circulation from a fan in the opposite corner of the house. Mean fall-out was 1.22 mm/day with fan, and 1.15 mm/day without.

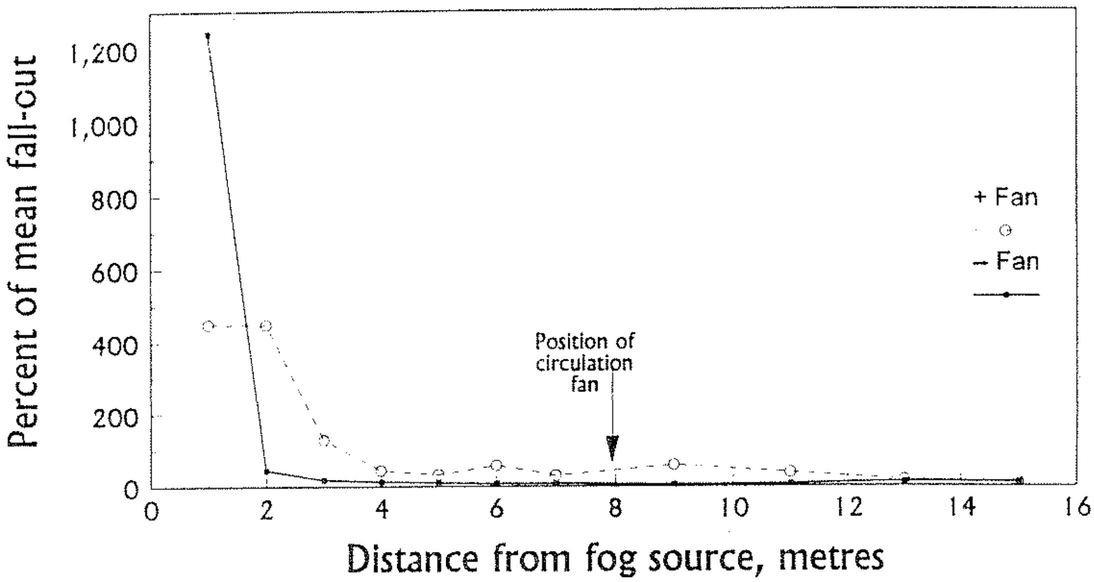

Figure 5. Fog fall-out from a single, vertical nozzle, set to produce "wet" fog (18 *l*/h water flow from a medium nozzle, using air 30 psi), with and without air circulation from a fan in the opposite corner of the house. Mean fall-out was 8.0 mm/day with fan, and 12.8 mm/day without.

Table 1: Percent rooting at various distances from the HDC fogger

	3 m	6 m	15 m
Trial 1, 7th August, 4 wks			
Ceanothus impressus	13	37	50
Cotinus coggygria 'Royal Purple'	100	100	100
Cornus alba 'Spaethii' LA79	100	100	100
Garrya elliptica 'James Roof'	100	25	0
Wisteria sinensis	63	100	50
Trial 2, 19th September, 6 wks			
Aristolochia macrophylla	100	50	50
Ceanothus impressus	50	38	38
Cryptomeria japonica 'Elegans compacta'	88	100	100

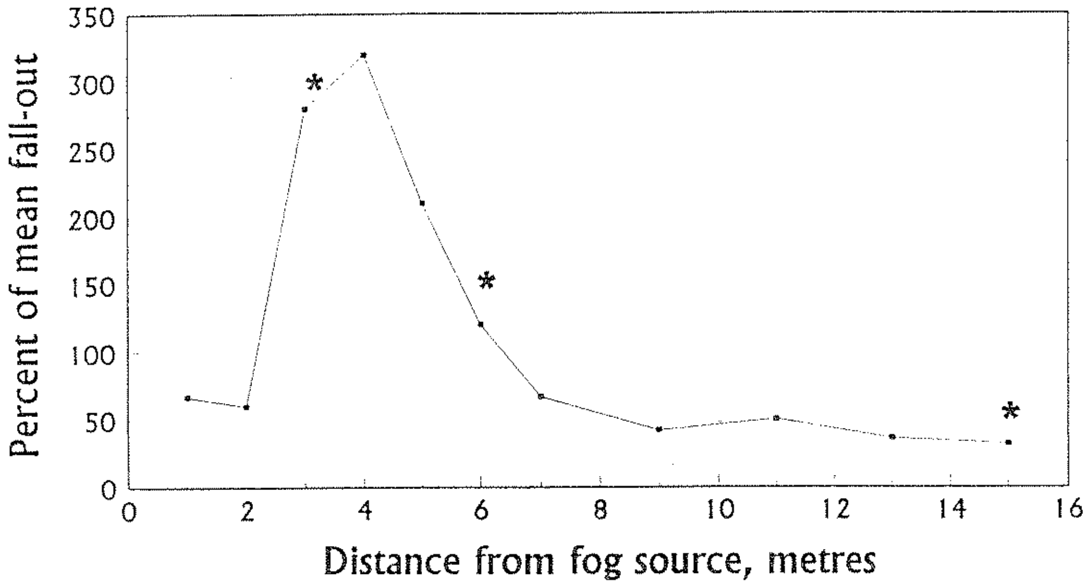

Figure 6. Fog fall-out from the HDC fogger set to produce a mixture of "wet" and "dry" fog for the 2nd rooting trial (1 medium nozzle with air at 30 psi, and 1 small nozzle with air at 65 psi, and total water flow of 35 *l*/h). It was operated with fan on, under evapostat control. Mean fall-out was 14.7 mm/day. The location of cuttings is shown by the asterisks.

The evapometric sensor

This sensor was first conceived as an alternative to a humidity sensor for fog control and has been applied increasingly in this rôle at East Malling as experience has proved its reliability. It has been found to require very little routine maintenance and is not easily damaged. Even more important is that there has been no need for frequent adjustments, either of the evapostat set point, or of the location of the sensor, as prevailing weather conditions varied. It has performed well controlling the HDC fogger, and the Agritech fogger, as well as "dry" fog from compressed air driven nozzles for both conventional cuttings, and for micropropagation. For the foggers that incorporate an electric motor, a cycle timer was added to the control system to reduce the frequency of switching. Although there has been no opportunity to compare two identical fog systems running side-by-side on the alternative control systems, from experience, we can confidently predict that the main difference would be that the evapostat would call for relatively less fog during cool cloudy weather but much more fog during potentially stressful hot sunny periods. This difference in response is illustrated by data from our indoor "Controlled Propagation Environment" facility in which it was possible to subject the control system to a series of abrupt and repeatable changes in light level by turning on additional lights. Figure 7 shows that, under evapostat control, the response to increasing light was both larger and faster than that observed under conventional humidistat control, as is appropriate to the cuttings' needs (Harrison-Murray *et al.*, 1993).

A common management response to high temperatures in propagation houses is to ventilate, and the response of the two sensors to the resulting decrease in humidity can be seen in Figure 8. The data show that the new sensor detected the drop in humidity just as well as the conventional sensor designed specifically for humidity measurement.

Since it is also sensitive to wetting, the evapostat system can also be used with mist. In this context a side-by-side comparison with a conventional mist controller was possible and clearly demonstrated the benefit of evapostat control. The contrasting response of the two controllers with respect to light is shown in Figure 9. Rooting results with *Acer palmatum* (Table 2) show the sort of benefit that might be expected; rooting percentage was almost 20% higher when the mist was under evapostat control. Although rooting percentage was higher still in a wet fog environment that was under timer control, leaf condition suffered severely from the continual wetting. Subsequently, by putting the same fogger under evapostat control, the benefits of maximum rooting have been combined with minimum leaf damage.

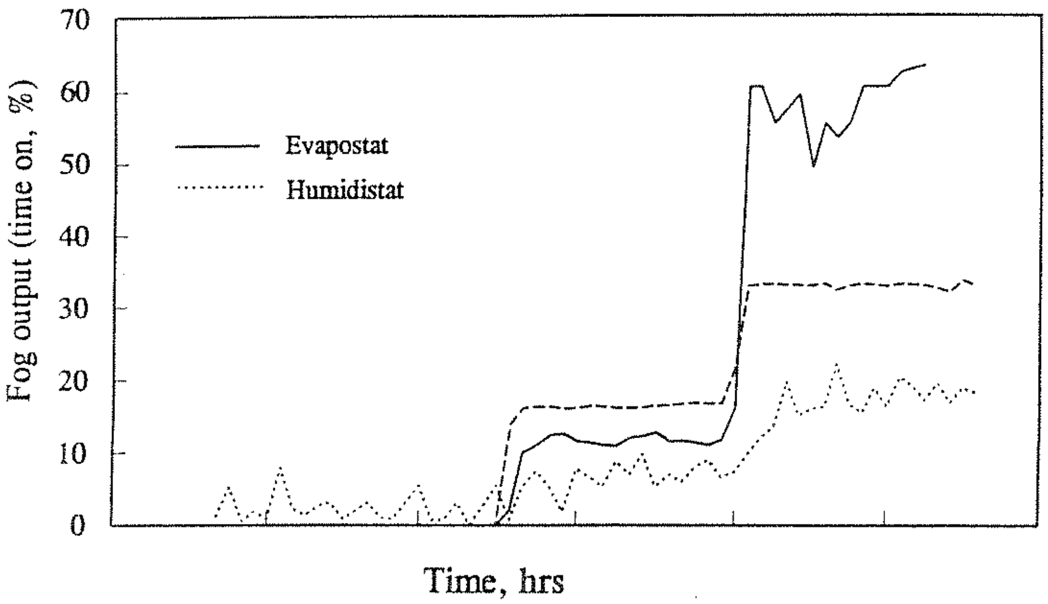

Figure 7. The effect of sensor type on response of a fog system to light. The graph shows the effect of a step-wise increase in light level (dashed line) on the output of a fog system operating under evapostat control (solid line), compared to the same system under conventional humidistat control (dotted line).

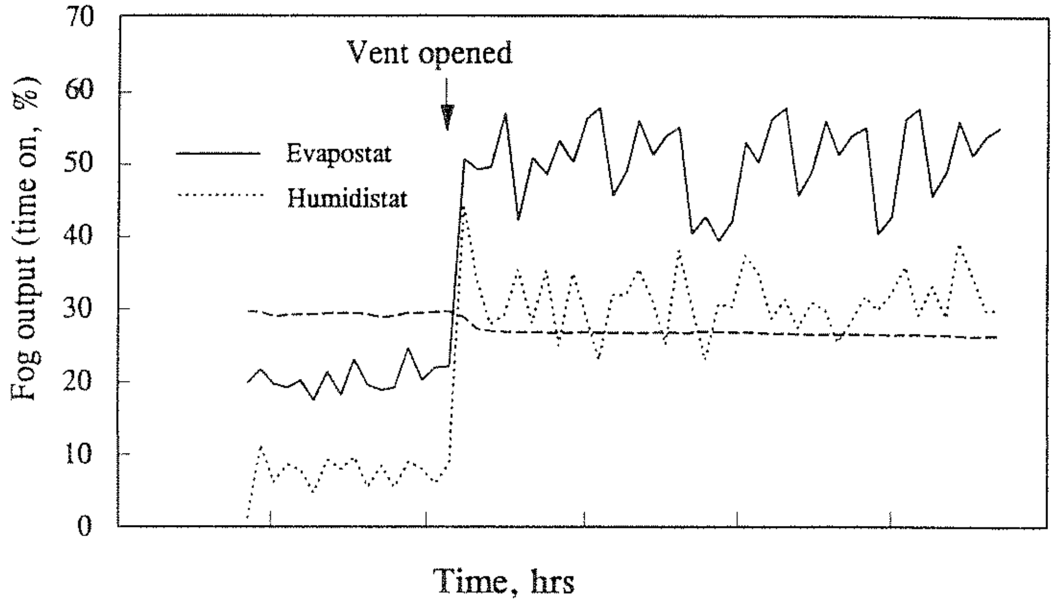

Figure 8. The effect of sensor type on response of a fog system to ventilation. The graph shows the effect of opening a vent on the output of a fog system operating under evapostat control (solid line) compared to the same system under conventional humidistat control (dotted line). Air temperature is shown by the dashed line.

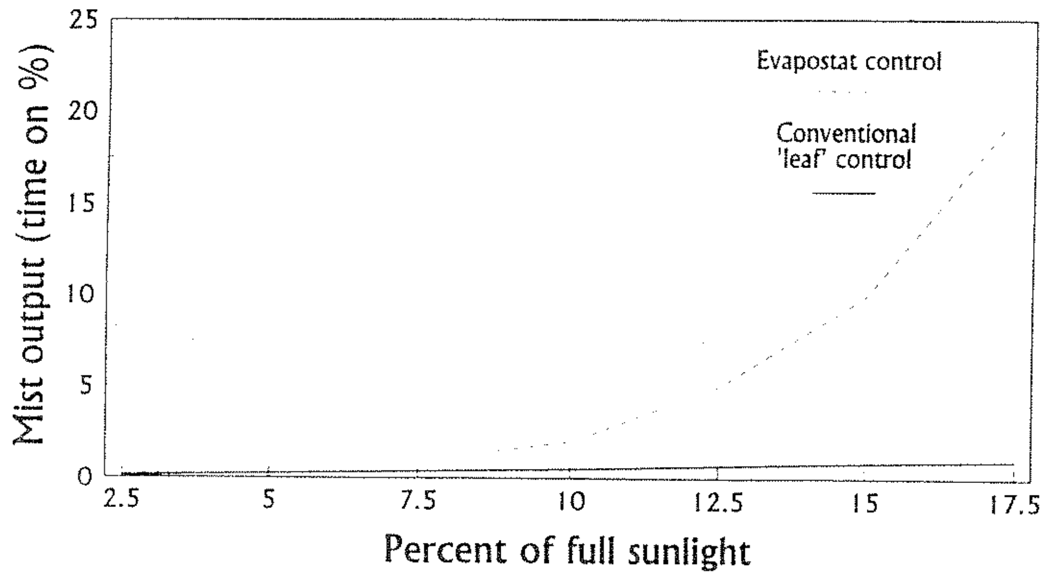

Figure 9. The response of a polythene enclosed mist system to increasing light when under the new evapostat control (broken line) compared to a conventional electric "leaf" type mist controller (solid line). Light measurements have been expressed relative to full sun in midsummer (taken as 2000 μmol m^{-2} s^{-1}).

Table 2. The effect of control system and environment on rooting and leaf condition of *Acer palmatum* 'Aureum', 5 weeks after sticking.

Environment	Control	Rooting, %	Healthy leaves per cutting [1]
Polythene-enclosed mist	Evapostat	75	4.7
Polythene-enclosed mist	Wetness ("leaf"-type)	56	4.7
"Wet" fog:			
2 m from fogger	Timer	69	0.9
9 m from fogger	Timer	88	2.0

[1] The number of expanded leaves without any necrotic area out of a total of approximately 6 per cutting.

Evapostat control of mist has been found particularly useful for weaning. The set-point on the control unit determines how stressful conditions must be before any mist is applied, and this set-point can be gradually increased as cuttings become better established.

Conclusions

So called "fog" can provide the essential mix of leaf wetting and high humidity (Harrison-Murray *et al.*, 1993) which many cuttings require to survive and root readily, but problems with existing equipment, particularly uneven wetting and inappropriate control systems, currently restrict its usefulness to nurserymen. Progress has been made in understanding these problems and some solutions are available.

Uneven wetting can be caused by variable water droplet size because larger droplets fall out rapidly, wetting cuttings close to the fog source. Small droplets remain suspended for longer and are carried much further before they are deposited or evaporate completely. The results obtained with the "HDC fogger" clearly showed the difficulties of exploiting this principle: even the very small droplets from sophisticated "ultrasonic" compressed air nozzles tended to fall out when the air stream carrying them encountered a solid object and was forced to turn sharply. This occurred even when the air movement was generated by the nozzle itself but was exacerbated by the turbulent air flow associated with the axial fan required to circulate the air around the whole propagation house. Any attempt to overcome the problem by generating yet finer fog would be ruled out on cost grounds. It must therefore be concluded that air circulation of fog will only achieve uniform wetting if a means can be found to create a gentle air circulation without the turbulence associated with axial fans. The results in Figure 4 (dotted line, from 0 to 7 metres) show the evenness of wetting that might then be achieved. Long centrifugal fans might be appropriate, as might very large diameter, slow moving, axial fans, but experimental assessment of such alternatives fell outside the scope of this project. Future work in this area might also examine the feasibility of an air flow along the length of the house with fans in a return duct where fall-out would not matter. The option of a non-recirculating air flow along the length of the house, as used in hot dry regions (e.g. California) is not suited to our climate, where such generous ventilation is rarely appropriate.

The "HDC fogger" also demonstrated that the performance of the Agritech fogger can readily be matched in ways that avoid some of its safety and reliability problems, and it is encouraging to note that equipment manufacturers are now beginning to make such equipment commercially available (e.g. the Priva Hygrofan). In essence, all that is required is to mount sufficient nozzles of whatever type on the front of a standard greenhouse fan. The motor needs to be reasonably well-sealed, but it does not have to be waterproof if baffles are used to deflect water deposition and it is regularly run long enough to drive off any water that has penetrated the casing. Depending on the shape of the house to be fogged, an oscillating system may also be needed. Of paramount importance is the provision of sufficient fog output to enable the fogger to humidify incoming air when forced ventilation is called for (at least 100 litres/hour for a 7000 m^3/h ventilation fan). In this respect high pressure water nozzles are likely to be preferable to the compressed air nozzles used on our experimental machine. In either case, it is clear from our results that a wetting gradient must be expected. A pragmatic approach to this "problem" is to exploit the range of conditions created to optimise survival, rooting and weaning once the environmental requirements of different varieties have been identified. This is immediately feasible for the many relatively small-scale producers that make up the bulk of the UK HNS industry. Large-scale producers should consider also the merits of having a number of single-fogger houses to increase the amount of relatively wet and dry propagation and weaning space.

For those large-scale producers insistent on seeking large-scale uniformity, at present the only option is to use a **large number** of nozzles (and therefore probably high pressure water nozzles) on overhead lines spaced sufficiently closely that there is considerable overlap of fall-out from adjacent nozzles. Such close spacing obviously increases capital and maintenance costs but **at normal spacing** the variation in wetting **around each nozzle** is often at least as large as that seen along a house equipped with a fan-distributed system such as the Agritech. Future research should examine the feasibility of mounting the array of nozzles in such a way that they could be oscillated slowly in the horizontal plane to blur these local variations.

Improving the performance of fog and mist systems for both rooting and weaning purposes will result from using the new evapostat control which reflects more accurately and responds more quickly than existing controllers to the tendency for cuttings to lose water to the atmosphere. An advantage of this is that in typically changeable UK weather cuttings are generously wetted during sunnier spells, but not blanketed in dense fog during dull periods. The evapometric sensor, in addition to controlling propagation systems, will enable nurserymen to monitor their own environments to assess the most suitable conditions and locations for particular cuttings, once typical requirements are identified in on-going work. It could also be incorporated into an alarm system to warn of the malfunction of fog or mist equipment, or of the need for manual intervention such as hosing down a polythene tent system.

Negotiations are continuing in an attempt to find a commercial manufacturer.

Glossary

Agritech fogger - a machine from the USA, in which fog is produced from 2 simple nozzles mounted on the ends of rotating arms. The rotation serves to pressurize the water and to create air movement around the nozzle which breaks up the water into a wide range of droplet sizes. It incorporates a fan, which in some versions shares the same motor as the nozzles, to distribute the very large output (up to 135 *l*/h).

Axial fan - a fan which blows air along its axis of rotation using a propeller. Most fans are of this type, including standard greenhouse fans, and that in both the Agritech and HDC foggers.

Centrifugal fan - a fan which blows air out at right angles to its axis of rotation using a cylindrical impeller. This type of fan is used in small fan heaters and in the large hot air curtain heaters often fitted above entrance doors to large shops.

Evapometric - involving the measurement or estimation of evaporation rate.

Evaporative demand - an imprecise term referring to the power of an environment to evaporate water. It differs from humidity, in that it also takes into account the many other factors which influence evaporation, such as wind. For a more precise definition it would be necessary to specify a particular evaporating surface.

Evapostat - a control system for maintaining a constant rate of evaporation from some particular type of surface; in the present context this is from leaves.

Potential transpiration - the maximum rate at which leaves could be losing water under prevailing environmental conditions. To achieve this maximum rate, water supply would be unrestricted and stomata would be fully open. Since stomata vary considerably even within one plant, it can only be given a precise value for a particular leaf. In relation to the new sensor, the term implies evaporation from an idealised model leaf, rather than any real leaf. How the behaviour of this model leaf compares with that of real leaves is the subject of current research, but it is clear that the similarity is close enough for the sensor to be of practical value.

Radiation - the form in which energy can be transferred between bodies without involving the material between them. For example, it is the only form in which energy from the sun can reach us across the vacuum of space. Its properties depend on wavelength, about half of the energy we receive from the sun (**solar radiation**) falling within the range of wavelengths that plants can use for photosynthesis and our eyes can detect, namely **light**. The visible waveband is only a small segment of the total spectrum of radiation which also includes ultraviolet, infra-red, radio, microwave, and many other wavebands.

Stomata - the pores in the outer layers of the leaf through which gas exchange takes place between the air spaces inside the leaf and the air around it. The size of the pore orifice varies in response to various factors including light, water shortage, and carbon dioxide. In this way the plant exercises some control on its transpiration rate.

Abbreviations used

kg/m^3 - kilograms per cubic metre.

***l*/h** - litres per hour. To convert to gallons per hour divide by 4.54.

m^3/h - cubic metres per hour. To convert to cfm (cubic feet per minute) divide by 1.7.

psi - pounds per square inch.

rpm - revolutions per minute.

References

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