Project title	Container Nursery Stock Irrigation: Demonstration and Promotion of Best Practice
Project number:	HNS 122 and 122a
Project leader:	Dr Olga Grant, East Malling Research
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Location of project:	East Malling Research, East Malling Darby Nursery Stock, Thetford, Norfolk W Godfrey & Sons Ltd., Surrey Hillier Nurseries, Brentry Hampshire Johnson's of Whixley Ltd., Yorkshire
Project coordinator:	The steering committee: John Adlam (Dove Associates) Chris Lane (Sevenoaks) John Richards (John Richards Nurseries) David Hooker (Hillier) Chris Burgess (private consultant)
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Key words:	Best practice, HNS, irrigation, sprinklers, water use efficiency

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

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Grower Summary

Headline

- Scheduling of irrigation according to plant demand, along with an irrigation system designed to maximize irrigation uniformity, resulted in substantial water savings, without reducing plant quality.

Background and expected deliverables

Public pressure to reduce water consumption combined with the potential benefits of improved irrigation management such as reduced water costs and a reduction in the labour costs associated with hand watering and grading plants, and improved uniformity and quality of plants all provide incentives for hardy nursery stock growers to improve irrigation management practices.

One of the aims of this project was to build on the survey of nursery water use in Project HNS 97, but this time monitoring individual beds with specified irrigation systems and crops in order to clarify variation in water use. Since HNS 97, significant improvements have been made in sensor technology for use in irrigation scheduling and therefore another objective of this project was to determine how useful these sensors are in practice, to compare their use, and determine what savings of water can be made.

To demonstrate and promote efficient and sustainable irrigation management practices for the HNS industry, the project incorporated two components. One was a demonstration and assessment of different beds, different irrigation systems, and different methods of irrigation scheduling on the East Malling Water Centre (EMWC). The other was to monitor water use on various nurseries around the country (water use monitoring scheme, WUMS). This work aimed to provide baseline data on water use on different nursery beds in different locations. It is hoped that growers will compare their own water use with that on the monitored nurseries, and will use the results from WUMS and the EMWC to improve irrigation management.

The project 122a, “Demonstration of gantry irrigation on an outdoor hardy nursery stock bed” was commissioned during the course of HNS 122, and is reported here to aid comparison with the other systems on the EMWC.

Another important aspect of this project has been to increase grower awareness of irrigation management.

Expected deliverables from this work were:

- Set up the East Malling Water Centre (EMWC), incorporating demonstrations of different irrigation systems and scheduling methods.

- Establish a water use monitoring scheme (WUMS) with grower participation.

- Provide information which can assist nurserymen in making sound investments when upgrading or expanding water management systems in their production areas.

- Deliver technology transfer activities in irrigation management including grower visits to the EMWC.

Summary of the project and main conclusions

East Malling Water Centre (EMWC)

The EMWC was constructed at the outset of the project and developed as a facility to demonstrate HNS irrigation systems. The centre incorporates different kinds of beds (Figure 1), with facilities for different methods of applying irrigation (Figure 2) and different methods of scheduling irrigation (Figure 3). In 2006 and 2007, newly potted liner crops in 3 L containers were monitored under the different systems over the growing season. The same mix of species was used with each system, to allow direct comparison of water use.

Figure 1. Different types of nursery stock beds on the EMWC: gravel (a), Mypex (b), and an Efford sand bed (c)

A standard gravel bed with rotoframes spaced 5 m apart and a timer set to turn on irrigation four times a day was used as a control against which other systems were compared. There was no attempt to alter irrigation times in accordance with weather or other conditions with this system.

- This basic unscheduled system used at least twice as much water as “improved” scheduled systems on gravel beds.

- The “improved” irrigation consisted of MP2000 rotator sprinklers spaced at 3 m between sprinklers along the edges of the beds (as specified by Revaho Ltd.). Uniformity of irrigation under this system was greater (Coefficient of Uniformity, CU of 83%) than under the more basic set-up (CU of 64%) – this is to be expected given that there was no overlap on the rotoframes bed from adjacent sprinklers.

Scheduling consisted of either daily adjustments to the length of time irrigation was turned on for according to Evaposensor readings, or automatic adjustments to maintain the percentage moisture in the substrate within a pre-determined window, using an SM200 soil moisture sensor and GP1 logger.

- A reduction in water use under the improved scheduled systems was achieved partly due to the need to irrigate excessively where irrigation is not uniform, in order to ensure that all plants on the bed receive sufficient water.

- Where scheduling is not used, it is not possible to adjust irrigation to the daily fluctuations in the weather.

- With scheduling, much water is saved on wetter, cooler or more humid days, when plant water use is limited and so irrigation is reduced or not applied.

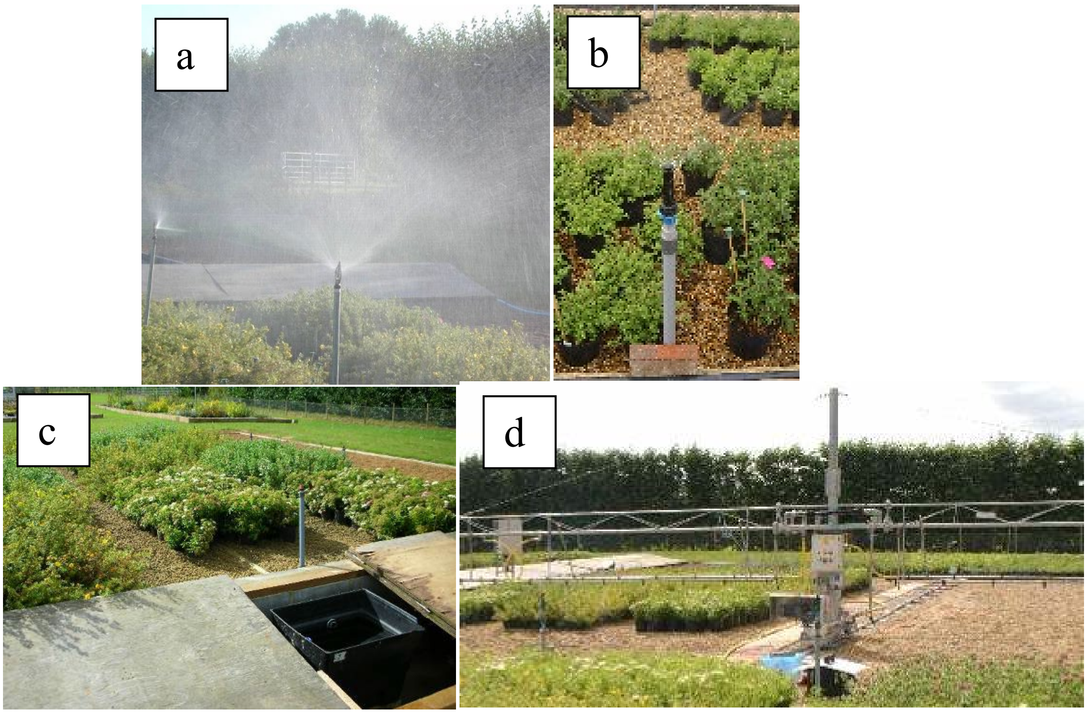

Figure 2. Different methods of applying irrigation on the EMWC: Conventional overhead irrigation by means of rotoframes (a) or MP2000 rotators (b), sub-irrigation (c), and gantry overhead irrigation (d)

On the gravel beds, both scheduling methods were effective, but overall less irrigation water was used with the soil sensor (Figure 4). This may relate to the greater difficulty associated with estimating the required reduction in irrigation after rainfall when scheduling with the Evaposensor. With the soil moisture sensor, irrigation will simply not be turned on if rainfall has sufficiently wet up the substrate.

When a gravel bed and a Mypex bed were compared using the same overhead irrigation system and same method of scheduling, it was found that less water was used on the Mypex bed. This difference was consistent over two years despite very different weather patterns. The Mypex drained more slowly and plants could take up more water during and after irrigation than on the gravel bed. However, poor drainage over winter on the Mypex bed appears to have had a deleterious effect on root quality. Although this is unlikely to affect the sale of plants, it would affect garden establishment.

Figure 3. Different technology for scheduling irrigation on the EMWC: Evaposensor and EvapoMeter (Skye Ltd.) (a) and soil moisture in-pot sensor with GP1 logger (Delta-T Devices Ltd.) (b)

Non-uniformity of overhead irrigation was seen to be a problem even with the "improved" system. This leads to non-uniformity of substrate moisture across beds and non-uniformity of plant growth and quality. Additionally, non-uniformity of water distribution makes scheduling more complicated. Production of plants with different demands for water on the same beds is an additional complication.

Total water use was less using a gantry compared to conventional overhead irrigation (when the same scheduling method was applied) and water application was more uniform under this system. The Efford sand bed used less water than any of the overhead-irrigated beds.

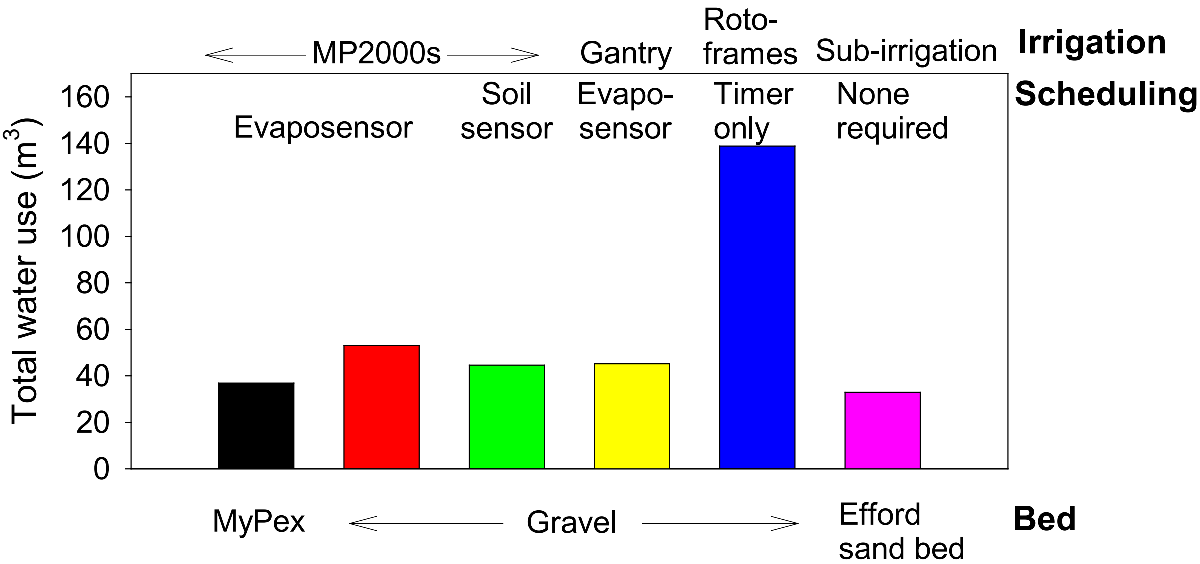

Figure 4. Water use on 10 m x 5 m nursery stock beds from the beginning of May to the end of September 2007. Different types of beds (Mypex, gravel, Efford sand bed), different methods of applying irrigation (MP2000s, gantry, rotoframes, sub-irrigation), and different methods of scheduling irrigation (Evaposensor, soil sensor, timer only, no scheduling requirement) were compared

Water Use Monitoring Scheme

A water use monitoring scheme (WUMS) was set up in 2005, with the participation of five commercial nurseries in different parts of England. Water use was monitored for three years (2005 – 2007). This work was developed to include comparisons of water use with different irrigation systems or of different methods of scheduling irrigation.

At one nursery in 2006, water use on a bed with MP Rotators was half that of a comparable bed irrigated with Mamkad sprinklers. Differences such as this generally reflect the importance of the arrangement of the sprinklers rather than just the type of sprinkler. Rotoframes were used very effectively on one nursery, where spray from several sprinklers overlaps to increase the uniformity of output; this is well-suited to nurseries where plants with similar water requirements can be grown on adjacent beds.

It was also noted that water was used much more efficiently and economically where some methodical scheduling practice was employed. At one nursery, use of the GP1 automatic irrigation system more than halved water use compared to grower-determined application of irrigation during the dry summer of 2006 (Figure 5), but had relatively little effect in the wetter summer of 2007. Use of a simple “bucket evaporimeter” on one nursery consistently led to low water use.

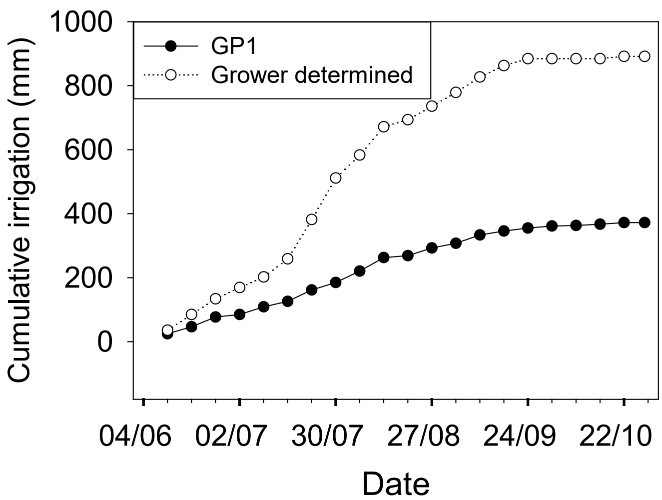

Figure 5. Cumulative weekly irrigation on two beds on a nursery in Hampshire in 2006. On one bed irrigation was scheduled using a GP1 automatic system (closed symbols). On the other irrigation was determined by grower experience (open symbols). The GP1 reduced water use by 60%

Conclusions

- The type and arrangement of sprinklers can improve the efficiency of irrigation.

- The use of sensors (soil or atmospheric) for scheduling can substantially reduce water use.

- In those systems which used the least volume of water, plants were of a similar or better quality than those systems with greater use of irrigation water.

Financial benefits

Improving irrigation management using overhead or sub-irrigation systems and scheduling reduces water use and also cuts down on costs such as checking edge plants, hand-watering, daily decisions regarding irrigation settings etc. However, capital costs and the cost of setting up and maintaining irrigation systems vary with the type of system. The most cost effective improvements will depend on the size and layout of a nursery.

Action points for growers

- Monitoring water use on HNS beds and monitoring irrigation distribution on different beds will identify wastage and determine where changes would yield the greatest gains.

- Use of the HDC Irrigation Calculator can help determine irrigation distribution and application rate for different sprinklers and sprinkler arrangements.

- It is important to determine the application rate for each HNS bed, and to know how much irrigation the plants will receive with different timer settings.

- Weighing some pots (a) before and after irrigation and (b) after a day of transpiration is a good guide to (a) plant water uptake and (b) rates of water use. The latter (b) needs to be repeated as plants grow.

- Scheduling of irrigation to match plant demand is beneficial in reducing water usage and improving uniformity.

- As a starting point, reading an Evaposensor or monitoring water loss from a bucket evaporimeter or using a soil moisture probe in some pots are good guides to crop water use and can help in good irrigation management. A hand-held soil moisture meter can alert the irrigation manager to areas on beds where plants are receiving too little or too much water.

- Consider how crops can be arranged in order to keep plants with similar water requirements together. If you have a range of bed types or irrigation systems, consider which is the most appropriate for each crop. For example, plants susceptible to foliar disease may need sub-irrigation. Then consider which other species have similar water requirements, and place them also on the sub-irrigated bed.

Science Section

Introduction

There is currently increasing interest amongst HNS growers in management of water use. This interest relates partly to increased concern over dwindling water supplies and legislation regarding their distribution e.g. UK Water Act 2003. Awareness that water supplies may be more limited in future has been heightened by recent water shortages during the summer, particularly in the south-east of England. In addition, there is increasing awareness amongst HNS growers of the advantages of good management of irrigation, including reduced labour costs as a result of improved uniformity of distribution of irrigation (limiting the need for hand-watering) and of improved uniformity of plant quality (reducing the labour requirement associated with grading of plants for marketing). Hence, more sustainable use of water can increase profitability and productivity.

HNS 97 made significant progress in developing irrigation scheduling techniques, and also highlighted improvements that can be made with irrigation systems – particularly overhead irrigation – to improve uniformity of distribution, and to use water more economically and in a sustainable fashion. Total water use on different nurseries was found to vary widely. HNS 122 therefore aimed to build on that work, but monitoring individual beds with specified irrigation systems and crops in order to clarify variation in water use. HNS 97 also indicated that water application could be reduced by 30-40% by scheduling irrigation to match crop evapotranspiration. Significant improvements have been made since HNS 97 in sensor technology for use in irrigation scheduling. One of the objectives of HNS 122 was to determine how useful these sensors are in practice, how they compare with each other, and what savings of water can be achieved with their use.

The ADAS Water Audit of container nursery stock nurseries in 2000 highlighted that 90% of smaller nurseries were dependent on mains water, which is relatively expensive. It also showed that the majority of nurseries use overhead irrigation, and that few recycle water. While inefficient irrigation systems were in use on the majority of nurseries, growers were willing to adopt improvements if their advantages could be clearly demonstrated, and training was available in the effective use of new systems. HNS 122 aimed to address those needs.

In order to demonstrate and promote efficient and sustainable irrigation management practices for container nursery stock nurseries, the project incorporated two aspects. One is the demonstration and assessment of different beds, different irrigation systems, and different methods of irrigation scheduling on the East Malling Water Centre (EMWC). At the

EMWC, the performance of existing and developing irrigation technology has been assessed in a more realistic setting than that to which the manufacturers of irrigation technology may have access. Such a site also overcomes the constraints that apply to demonstration trials on commercial nurseries where the need to supplement irrigation with hand-watering to guarantee optimum quality can mask differences between systems. The information can then be disseminated to both hardy nursery stock growers and irrigation technology companies. In the longer term, assessment of plant performance under different systems will allow protocols to be developed for best irrigation practice on nurseries. The other aspect of this project is the monitoring of water use on various nurseries around the country. This is a step towards the provision of baseline data on water use on different nursery beds in different locations. It is hoped that other growers will compare their water use with that on the monitored nurseries, and will use the results of both the monitoring on nurseries and research on the EMWC to decide on suitable improvements to irrigation management that suit their specific nursery. An important aspect of this project has been to increase awareness of irrigation management.

HNS 97 (Water LINK I) showed large variation between nurseries in water use. Building up a picture of water use on different nurseries will assist in determining how and where water use on nurseries in general can be reduced. HNS 97 also indicated that a substantial reduction in water use can be obtained by regulating irrigation to match evapotranspiration (ET_p). We are building on this work in HNS 122, regulating irrigation on some beds to match ET_p, and on another to maintain constant soil moisture. In this project we are doing this on small but realistic nursery beds, with overhead irrigation. Thus we are moving regulation of irrigation from an artificial experimental set-up forward to a realistic demonstration of a system that is possible to implement on a nursery with existing irrigation. Finally, in HNS 97 and now HNS 141 (Water LINK II), the potential advantages of applying a deficit irrigation regime are being studied, but information as to how well regulation of irrigation performs under existing nursery systems is required to determine how realistically such a deficit regime would work in commercial situations.

Materials and Methods

Objective 1. Set up the EMWC, incorporating demonstrations of different irrigation systems and scheduling methods.

The EMWC was constructed and developed to become a working facility for the demonstration of hardy nursery stock irrigation systems (Figure 1). The centre incorporates different kinds of beds (Figure 2), with facilities for different methods of applying irrigation (Figure 3) and different methods of scheduling irrigation (Figure 4). The combination of bed-type, irrigation system and scheduling method is as follows:

Beds:

10 m x 5 m beds drain into a culvert, and a larger bed has been divided into three sections for the purpose of the current project (Figure 5). The larger bed (D-F) and one of the smaller beds (A) are gravel beds; of the remaining smaller beds one consists of Mypex over polythene (B), and one is a sand bed in the Efford style (C).

Irrigation systems:

In the Efford sand bed system irrigation is provided via a tank at the end of the bed – the sand wets up and the media in the pots takes up water from the sand below by capillary action. There are three overhead sprinkler irrigation systems. One of these is a traditional rotoframe system (on Bed F), which is commonly used on nurseries. Three other beds (A, B, D) have MP2000 nozzles on risers along the edges of the bed, spaced so as to maximise the uniformity of irrigation on the bed. These nozzles are adjustable – the arc and radius of the projection of irrigation can be altered to suit the bed – and are considered to be an improvement in overhead irrigation compared to earlier less precise sprinklers. The rotoframes were provided by Evenproducts and the MP2000 systems by Revaho. These companies advised us as to suitable spacing of these systems on our 5 m x 10 m beds. The rotoframe beds consists of two rotoframe sprinklers spaced with 5 m between them. The MP2000 rotator sprinklers are spaced at 2.5 m between sprinklers along the edges of 10 m x 5 m beds, with the arc of the sprinkler projector set at 210° except on the corners, where the arc was set to 100°. The rotoframe system is intended to be a "typical" system, and water distribution was expected to be uneven. This allowed comparison of water distribution and the effects of that distribution on plant growth, quality, and uniformity under a "typical" system and under "improved" overhead irrigation. A gantry overhead irrigation system was installed in 2006 on part of the large gravel bed. This was specifically requested by the steering committee in January 2006 and approved by the HNS Panel later in the year, as project HNS 122a. It was expected that this system would provide more uniform irrigation than traditional overhead. The gantry is manufactured by the German company Rathmakers.

It is a robust machine, as required for outdoor use. It can operate in either of two gears and at several speeds, which determine the rate of irrigation. In addition to having irrigation sprinklers, there is a separate set of sprinklers which can be used with a Dosatron for fertigation or spraying. The gantry has two arms and it is possible to turn off an arm or half an arm while irrigating from the remaining sections.

Figure 1. Development of the East Malling Water Centre (EMWC) from a field through to a fully-functioning demonstration site.

Figure 2. Different types of nursery stock beds on the EMWC: gravel (a), Mypex (b), and an Efford sand bed (c).

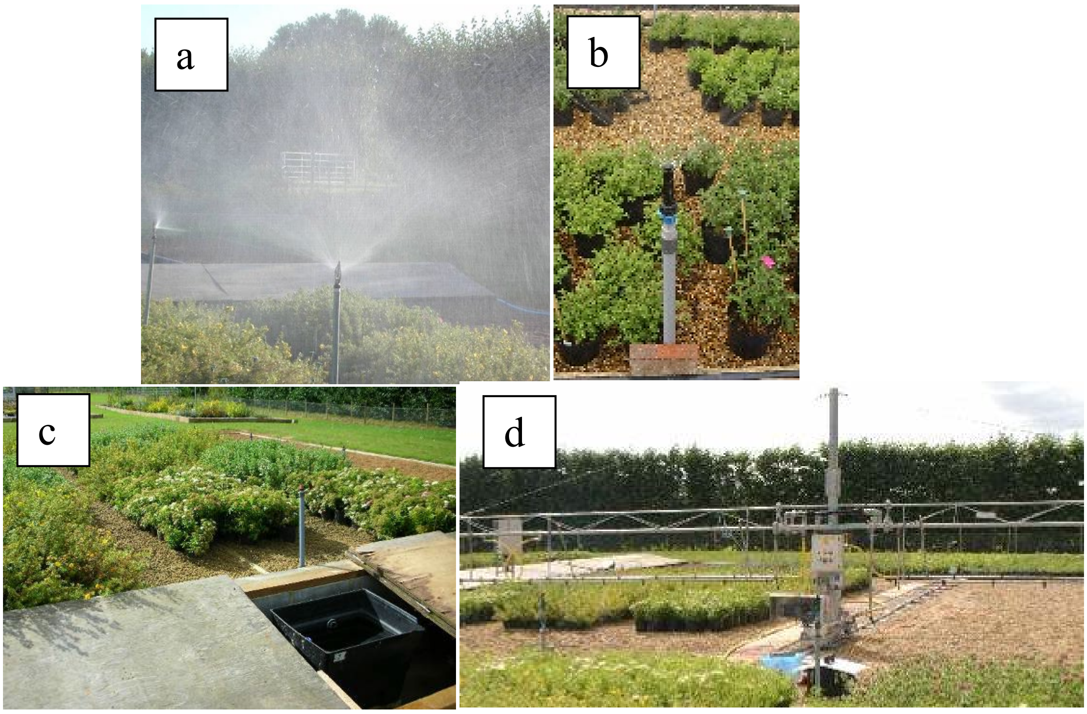

Figure 3. Different methods of applying irrigation on the EMWC: Conventional overhead irrigation by means of Rotoframes (a) or MP2000 Rotators (b); sub-irrigation (c); and Gantry overhead irrigation (d).

Figure 4. Different technology for scheduling irrigation on the EMWC: Evaposensor and EvapoMeter (Skye Instruments Ltd.) (a) and soil moisture sensor and GP1 (Delta T Devices Ltd.) (b).

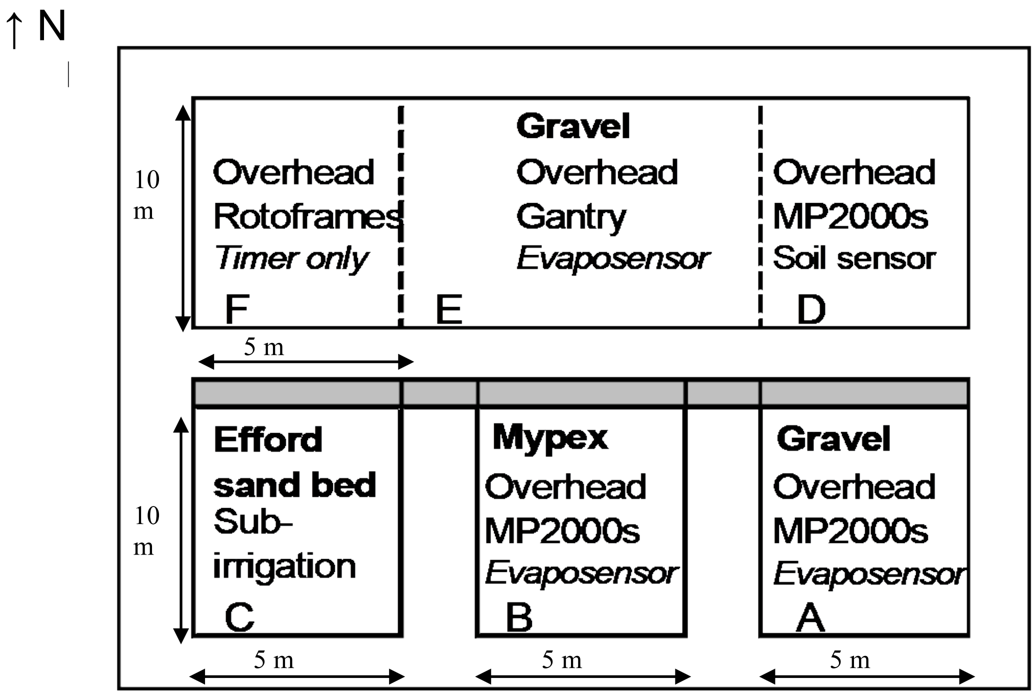

Figure 5. Layout of beds A-F on the EMWC, showing the different types of bed (in bold type), the different types of irrigation system (plain text) and the different technology used for scheduling, where applicable (italics).

To determine the application rate and uniformity of distribution under the different sprinklers, catch pots have been used on each of the beds at 1 m intervals to collect water during 5 mins of irrigation. The captured water in each pot was measured and the HDC Irrigation Calculator used to determine the mean application rate and coefficients of uniformity and scheduling (see HDC Factsheet 16/05):

1. Mean application rate (MAR) in mm of water received on the bed per hour of irrigation.
2. Christiansen's Coefficient of Uniformity (CU): this is the average difference between the catch in each saucer and the average catch (absolute value) over the average catch, and is expressed as a percentage.
3. Scheduling Coefficient = MAR/lowest catch rate

This was repeated on a number of different dates, including still and windy days to determine the impact of wind speed on uniformity.

In addition, run-through was determined by placing the pots in larger containers with plastic liners, and measuring water delivery to the plant pot (weight gain) and the quantity of water running through into the container below. This was carried out for each overhead system at a range of run lengths (or speeds in the case of the gantry) corresponding to typical run lengths/speeds used during the summer.

Scheduling:

In the case of the rotoframes, irrigation was not adjusted to daily fluctuations in the demand of the plants for water. On three of the beds, however, irrigation is adjusted to allow for such fluctuations. On two of these beds (A and B) application of water was matched to evaporative demand. To achieve this, an "Evaposensor" (Skye Instruments Ltd., Powys) was used, which has two temperature sensors, one dry and one kept wet with a wick in a small reservoir of water. This sensor is attached to a meter (the "Evapometer") which records the difference in temperature between the two sensors and records "degree hours", where 1 degree hour is a difference of 1 degree Celsius between the wet and the dry sensors over a period of one hour. The accumulated number of degree hours over a day was monitored. By weighing the plants after they have been well irrigated and a day later, how much water the plants use per degree hour was calculated. After this calibration, it is only necessary to read the Evapometer every day to know how long we need to irrigate to replace the water the plants have lost through evapotranspiration. The calibration, however, needs to be repeated at intervals as the plants grow, since they use more water per degree hour when they are larger. The calibration was carried out after the plants were placed on the beds and at intervals thereafter. Two plants per block i.e. 8 plants per species (see below) on either bed were used in the calibrations. Since an Evapometer was used to schedule irrigation on a gravel bed and on a Mypex bed, and since the irrigation system was the same (MP2000s), differences in water use and plant growth, quality and uniformity resulting from the two different types of bed surface can be directly compared. To determine how much water the plants received in a given length of irrigation, in 2006 values were obtained by collecting water in saucers over the bed during an irrigation run of 5 minutes. However, it became clear during the season that plants on the Mypex were taking up additional water from the surrounding Mypex. Therefore plants were weighed before and after irrigation to see how much water they were taking up, and the calibration for the Mypex bed was adjusted accordingly. This means that for the latter part of the season, plants on the Mypex bed were given less irrigation per degree hour than plants on the gravel bed. In 2007 plant weight before and after irrigation was used to determine how much water plants took up during an irrigation event. Plants on the Mypex bed gained more weight during an irrigation event, and therefore were given less irrigation per degree hour than plants on the gravel bed.

Irrigation on the gantry-irrigated gravel bed was also scheduled using an Evapsensor in 2007. The gantry runs at several different speeds, with plants receiving more water in an irrigation run at lower speeds. Saucers were used (as above) to obtain information about the uniformity of gantry irrigation, and plants under the gantry were weighed before and after irrigation to determine how much water they were taking up during an irrigation run. This was determined at a number of different speeds to construct a relationship between speed setting and water delivery. From this, the speed necessary to replace different numbers of degree hours of evapotranspiration was determined. Each day, the correct speed was selected to replace the amount of water lost from the plants the previous day. Since the gantry was run over a gravel bed, and since irrigation on this bed was scheduled with an

Evaposensor, it is possible to directly compare water use on the gantry bed with water use on Bed A – also a gravel bed, scheduled by means of the EvapoSensor, but with "conventional" overhead irrigation. Thus it is possible to see whether any water was saved, or plant growth or quality improved, using gantry irrigation.

On another bed a soil moisture sensor (SM200, Delta T Devices Ltd., Cambridge) in the substrate in one of the pots measures the volumetric moisture content. This sensor is connected to a small logger (GP1) which both monitors the soil moisture over time and controls whether or not the irrigation is turned on. If the substrate is sufficiently wet, the irrigation stays off. If the substrate moisture falls below a determined value, however, then the irrigation turns on. This system was installed with the help and advice of Chris Nicholl from Delta-T Devices Ltd. Initially, a suitable value at which irrigation would turn on had to be determined. After experimenting with some different values it was decided that 35% moisture (by volume) in the substrate was suitable to maintain the substrate in a well-watered but not overwatered state. The GP1 was used with a battery-operated timer (Galcon). With such a timer, it is necessary to set the irrigation to go on at certain times of day (in our case 8, 12, 16 and 20 h) for a certain length of time (15 mins in this case). If the substrate moisture is below 35% the irrigation turns on and stays on for 15 mins. The next time the irrigation is set to turn on, if the substrate moisture has not reached an upper set value (50% in this case) then the irrigation will turn on. This will continue until the substrate moisture reaches the upper set value. Once the substrate moisture is above the upper value, then the GP1 will override the signal from the solenoid timer and the irrigation will stay off. The irrigation will not go on again until the substrate moisture falls to 35% (Figure 6). It should be noted that with an electrically-operated timer the GP1 works slightly differently. In that case the irrigation would be turned off *during* an irrigation run if the soil moisture reaches the upper set value. In 2007, after studying substrate moisture data for different beds in 2006, we decided that we had perhaps been running this bed a little wetter than necessary. Therefore the thresholds for turning irrigation on and off were changed to 30% and 45% respectively.

Since it is known that overhead irrigation is not entirely uniform, any scheduling system cannot necessarily schedule irrigation optimally for *all* plants on a bed. In addition, where different species are grown on the same bed, they will not necessarily use water at the same rate, so it is impossible to irrigate them all to exactly replace the amount of water they use, without over-irrigating some, using an overhead system. We therefore had to decide whether to irrigate to suit the area of the bed that receives the least water and the species that uses the most, or to irrigate to suit the area of the bed that receives the most water and the species that uses the least, or to irrigate to suit the average plant on the bed. We chose the latter, so how much water the average species was using was determined and irrigation runs were set according to what the average pot on the bed receives on a still day. This was chosen so that the effects of non-uniform irrigation and of growing different species together could be clearly demonstrated. However, later in the season *Potentilla* used more water than the other species (see later for species information) and due to its sensitivity to water deficits had to be used as the "control" species. Therefore the other species on the beds will in general have received more water than necessary at that stage.

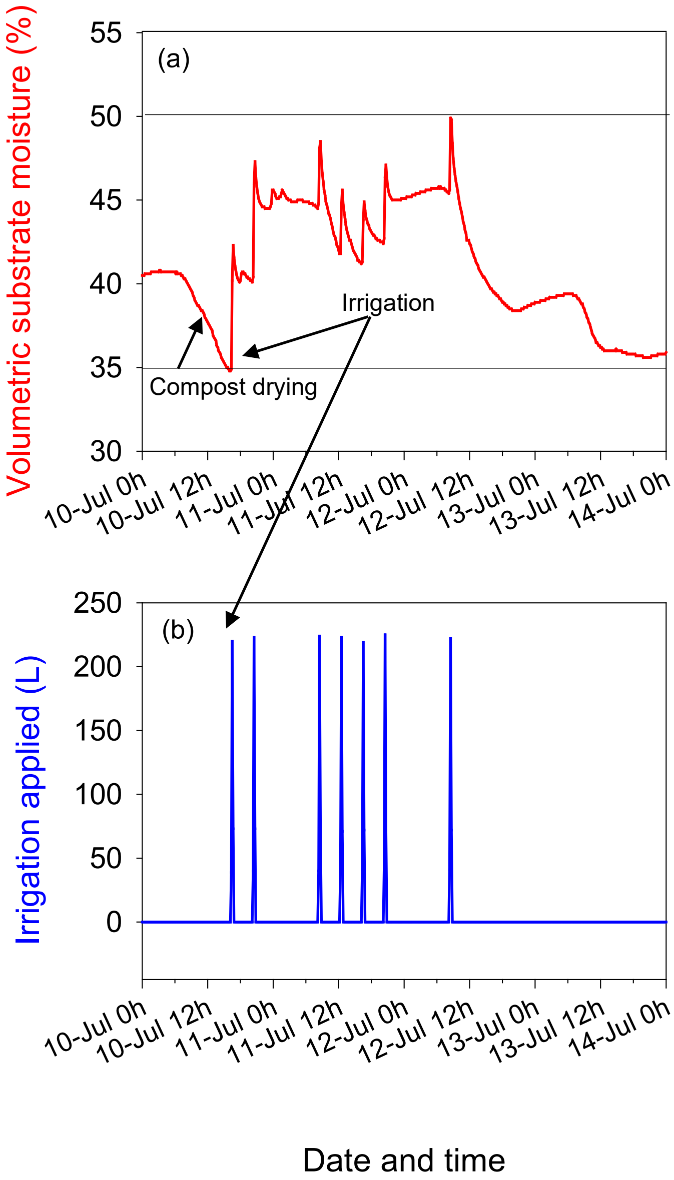

Figure 6. A typical sequence showing the interaction of compost moisture and irrigation. When volumetric compost moisture falls below 35% (a), irrigation goes on (b), but once soil moisture reaches 50%, irrigation does not go on again until the soil moisture falls below 35% again. This is the mode in which a GP1 operates when connected with a battery-operated timer.

Objective 2. Establish a Water Use Monitoring Scheme (WUMS) with grower participation.

Monitoring irrigation use

In the first growing season (2005), five contributing nurseries each monitored water use on an overhead irrigated outdoor crop. The nurseries were located in Yorkshire, Hereford, Norfolk, Hampshire, and Surrey (Figure 7). Monitored beds were fitted with a separate water meter. Complete standardisation of crop, pot size, potting date etc. was not possible between sites, but most grew a broadly similar 'spring potted liner crop' in 2 or 3 L containers, and specific crop details that are likely to influence water requirements were noted for each site. Details are provided in Table 1. Nurseries were also visited initially to record sprinkler type and layouts, standing base material, cropped areas etc. and to measure irrigation system application rates and uniformity.

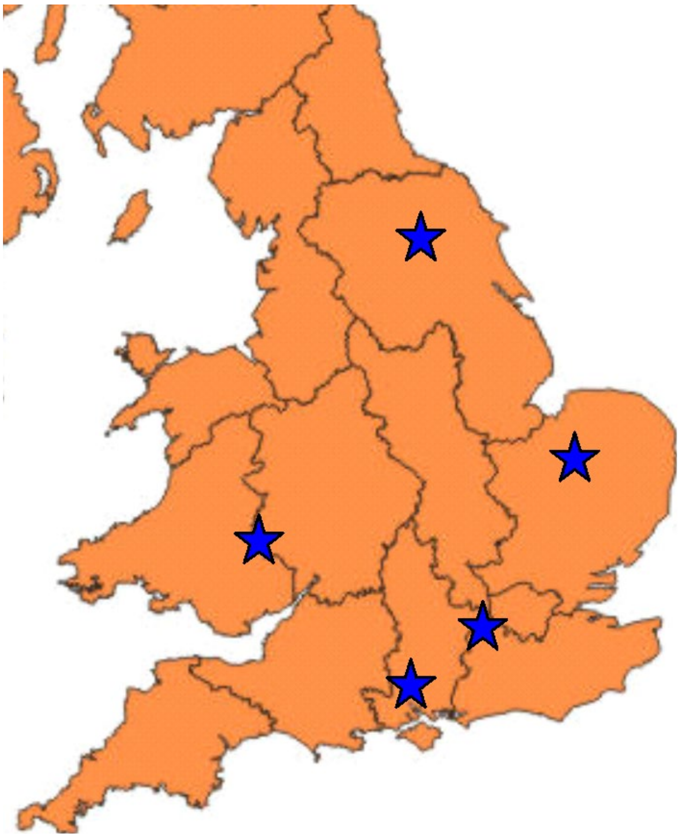

Figure 7. Location of the 5 nurseries participating in WUMS.

All growers routinely recorded the following from 6th June to 18th September (apart from at the Norfolk nursery where records were kept from 4th June to 26th August):

- Irrigation dates (scheduled according to grower's usual practice)
- Water consumption after each irrigation (meter readings)
- Daily rainfall (rain gauge)
- Evapotranspiration estimates (Skye Evaposensor and Evapometer)
- Observation on crop stage of growth and other comments

Each nursery's Evapometer and rainfall data provide common environmental measures against which water consumption can be referred. Water use for the different nurseries can then be examined in relation to the other two key factors affecting consumption: the crop (type and size) and efficiency of water application. Apart from the Surrey nursery, the nurseries were not routinely using any methodical scheduling to decide when and how much to irrigate, but rather relying on judgment by the irrigation manager to set appropriate timeclock settings on the irrigation controller. At the Surrey nursery, however, a simple 'bucket evaporimeter' was used (Figure 8), as described in the report for HNS 38 (1993-1995) as a basis for irrigating beds of herbaceous subjects.

Figure 8. Bucket evaporimeter on use on the Surrey nursery. Evaporation of water from the bucket is used as an indication of evapotranspiration, and irrigation is adjusted accordingly.

In the second year of the project, nurseries were given the option of extending their monitoring to include a simple "two treatment" comparison e.g. to compare irrigation systems such as areas with different sprinkler types or layouts, or to compare scheduling methods such as a standard manual / timeclock control vs. automatic scheduling using an in-pot moisture probe (Table 2).

Four of the five nurseries involved in the WUMS in 2005 also participated in the scheme in 2006. All were using overhead irrigation on outdoor crops in pot sizes 2 – 3 L. At the Norfolk nursery, two separate beds were monitored. Both had the same kind of sprinklers, but on one bed they were spaced close together, while on the other wide spacing between sprinklers was used. The "bucket evaporimeter" was used again on the Surrey nursery. At the Hampshire nursery, one bed was 'manually' scheduled conventionally, and water use on this bed was compared to that on another bed using Delta-T's in-pot SM200 moisture probe and GP1 logger and irrigation controller (Figure 9). Two SM200 probes were used, both initially being inserted into separate containers of the green *Spiraea* 'Little Princess'. Probe 'Moisture 1' was programmed by the GP1 to control the irrigation by switching the irrigation solenoid on and off according to upper and lower growing medium moisture level set points.

Probe 'Moisture 2' was inserted in a second pot to replicate moisture level monitoring but with no control function. The probes were inserted near to the centre of the container and partly buried so that the sensor pins were in the centre zone of the rooting medium. The GP1 unit was installed on 16th May. The master irrigation control panel was set to provide power to the solenoid irrigation valve wired in series with the GP1 control relay for 1 hour at 16:30 and 21:30 each day. Irrigation events were moderated by the GP1 with initial moisture set points of 30% on / 40% off with a check frequency of 20 mins x 25% duty cycle to provide pulsed irrigation i.e. once the moisture level in the controller pot fell below 30%, the relay switched between 5 min on (irrigation) and 15 min off (soak-in) cycles, until irrigation had rewetted pots to above the 40% level. While the GP1 might call for water at any time, irrigation would only occur within the twice daily one hour opportunities set by the pump-house control panel, thus moisture levels might fall below 30% before irrigation started on hot days. Based on crop observations and recorded data, the set points were changed to 35% on / 45% off on 2nd June. On 12th June the duty cycle was increased to 50% (i.e. 10 mins on / 10 mins off) to give more time to apply water within the available irrigation opportunities. On 16th July, the controller probe was moved to one of the *Physocarpus* pots as this crop on part of the bed was demanding more water than the *Spiraea* and was requiring some occasional hand watering top-ups. The second monitoring probe was retained in the *Spiraea* (Figure 13). Finally, on 5th September the set points were changed to 40% on / 45% off and a 5 min check frequency x 100% duty cycle to see whether a tighter moisture fluctuation regime could be achieved.

Water use etc. was recorded from 5th June to 17th September in 2006.

In the third year of the project, the comparison of GP1 *vs.* grower-determined irrigation was repeated at the Hampshire nursery, and monitoring of irrigation use under rotoframes and with the assistance of a bucket evaporimeter for scheduling was continued at the Surrey site. A comparison of GP1 *vs.* grower-determined scheduling was also undertaken on the Norfolk nursery. Details of the beds etc. are in Table 3. Water use etc. was recorded from 4th June to 26th August, except at the Norfolk nursery where recording started on 18th June.

Calculation of irrigation efficiency

Rainfall in excess of 5 mm per day may be regarded as “wasted”, as typically more than 5 mm of uniform rainfall would be more than enough to fully wet the containers (however, to what extent this assumption holds will depend on the intensity and angle of the rainfall and needs testing). The quantities of “useful rainfall” each day was determined for each of the participating nurseries. “Useful precipitation” was calculated as the sum of the irrigation applied and the useful rainfall. From this, the contribution of rainfall to meeting the water requirements of crops on each bed was determined.

Figure 9. This entire bed on the Hampshire nursery was controlled with one soil moisture probe (right inset) connected via a GP1 (left inset) to the irrigation solenoid.

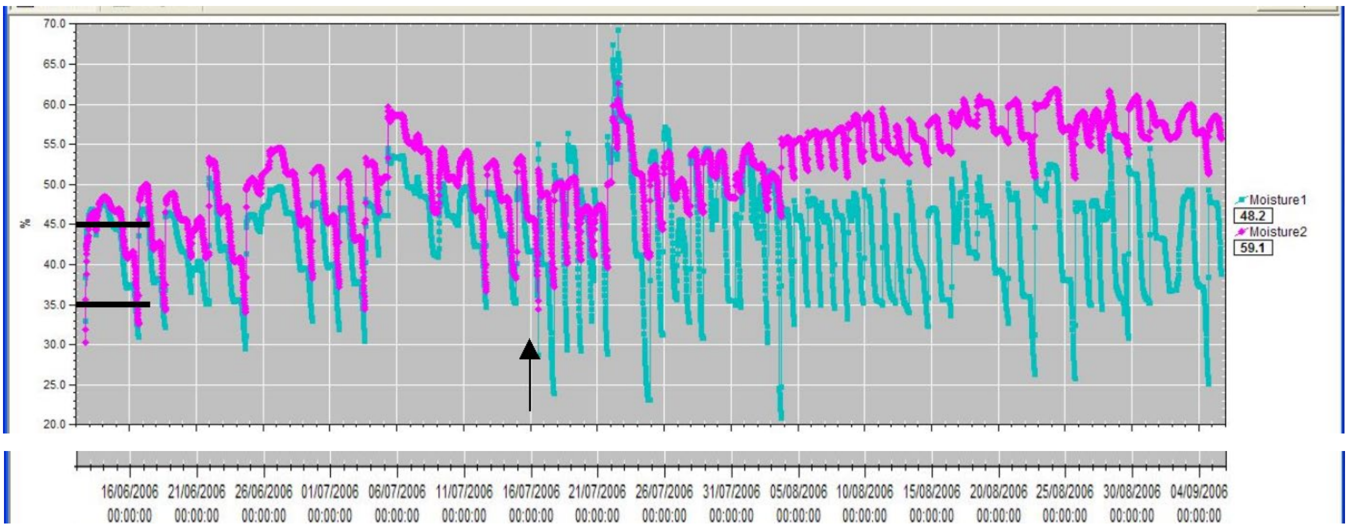

Figure 10. Percentage substrate moisture in the controlling pot (moisture 1) and in a second pot (Moisture 2) on the bed in Hampshire controlled with a GP1, in 2006. The arrow indicates when the controlling probe was moved from *Spiraea* to *Physocarpus*.

Table 1. Details of beds, sprinkler layouts, and crops monitored in 2005. "Grower" indicates grower-determined application of irrigation.

Location	**Bed**	**Sprinklers**	**Scheduling**	**Crop**
Yorkshire	Mypex on polythene sloped to central collecting channel 18 m x 85 m = 1530 m^2	3 lines Super Mamkads 7 m apart x 8 m in-line Centre line Ivory nozzles 335 L h^{-1}; outside lines Red 670 L h^{-1}	Grower	3 L *Viburnum*
Hampshire	Mypex on polythene sloped to central drain 15 m x 39.3 m = 590 m^2	Naan 427-AG impact sprinklers 4.0 mm 850 Lh^{-1} @ 2 Bar Approx 7.0 m apart down bed edges set at 180° arc	Grower	2 L *Spiraea*
Hereford	Mypex	Rainbird impact	Grower	3 L *Physocarpus*, 2 L Rosemary
		MP Rotators	Grower	3 L *Olearia*
Norfolk	Gravel – hard standing base	Widely spaced Naan 423-AG brass impact sprinklers 850 L h^{-1} @ 2 Bar	Grower	3 L *Clematis*
Surrey	Gravel 23.5 m x 10 m = 235 m^2	2 rows Rotoframe sprinklers (950 Lh^{-1} @ 2 Bar) 5.0 m x 5.0 m 5.75 m between lines of adjacent beds.	Bucket evaporimeter	9 cm herbaceous

Table 2. Details of beds, sprinkler layouts and crops monitored in 2006.

Location	Bed	Sprinklers	Scheduling	Crop
Yorkshire	Mypex on polythene sloped to central collecting channel 18 m x 85 m = 1530 m^2	3 lines Super Mamkads 7 m apart x 8 m in-line. Centre line Ivory nozzles 335 L h^{-1}; outside lines Red 670 L h^{-1}, until 7 June. Then 7 of 11 centre line nozzles replaced with Naan 437-AG 4.0 mm impact sprinklers 850 L h^{-1} 180° arc.	Grower	Lavenders 3 L and Grasses 3 L.
		3 lines MP Rotator sprinklers 9 m apart x 5 m in-line Windward edge and centre lines on full circle operation (283 L h^{-1} @ 2 Bar); leeward edge line at 210° arc (165 L h^{-1} @ 2 Bar)		Mainly *Viburnum tinus* 3 L plus some Lavenders 3 L
Norfolk	Gravel – hard standing base 43 m x 40 m = 1720 m^2	Naan 423-AG brass impact sprinklers 850 L h^{-1} @ 2 Bar 18.5 m x 9.25 m in staggered rows	Grower	Mainly *Sambucus* 3 L
	Gravel – hard standing base 24 m x 72 m = 1728 m^2	Naan 423-AG brass impact sprinklers 4.0 mm 850 Lh^{-1} @ 2 Bar 6 m x 6 m		
Hampshire	Mypex on polythene sloped to central drain 15 m x 39.3 m = 590 m^2	Naan 427-AG impact sprinklers 4.0 mm 850 Lh^{-1} @ 2 Bar. Approx 7.0 m apart down bed edges set at 180° arc.	Grower	Mainly *Spiraea* cultivars in 3 L. Some *Cotinus*.
			GP1	Mainly *Spiraea* cultivars in 3 L Some *Physocarpus*.
Surrey		As 2005		Mainly *Penstemon* 2 L.

Table 3. Details of beds, sprinkler layouts and crops monitored in 2007.

Location	Bed	Sprinklers	Scheduling	Crop
Norfolk	Sand	Naan 423-AG brass impact sprinklers 850 L h^{-1} @ 2 Bar	Grower GP1	*Philadelphus* 3 L
Hampshire		As 2006		*Spiraea* 3 L
Surrey		As 2006		Heucheras 2 L

In order to compare water use on nurseries in different locations, where weather conditions differ, a water use index (WUI) was devised. This is a ratio of "water use" to degree hours measured with the Evaposensor, and is expressed as mm irrigation/100 °C h. "Water use" in this case is mm irrigation plus useful rainfall i.e. useful precipitation.

The average daily quantity of irrigation applied, useful precipitation, Evaposensor degree hours, WUI, and useful rainfall as a percentage of useful precipitation was calculated for each bed in order to obtain seasonal values.

Objective 3 Provide information which can assist nurserymen in making sound investments when upgrading or expanding water management systems in their production areas.

In order to allow growers to use the work being carried out at the EMWC, we not only demonstrated different systems, as described in Objective 1, but also monitored crops on these systems, allowing detailed information regarding water use, plant development, and plant quality, to be obtained for each system. This allows a comparison of systems, which growers can then relate to their own nursery, and take on board if expanding or improving irrigation on their nurseries.

Monitoring of crops on the EMWC

Semi-mature plants in 3 L pots were used to calibrate and test different systems in September 2005. This involved determining the water use of a range of species in relation to degree hours measured with an Evaposensor, both on an open bed and under polythene, calibrating water use of the plants against the output from different irrigation systems, and becoming familiar with a prototype GP1 system.

In 2006 and 2007, to compare water use on different beds, the same numbers of plants and same species on each bed were used. The species used in 2006 were: *Cistus creticus, Potentilla fruticosa* "Tangerine", and *Spiraea nipponica* "Snowmound". These were purchased as liners from New Place Nurseries in June 2006 and potted up into 3 L pots in a 100% peat substrate in Hillier nursery before being delivered to East Malling Research where they were immediately placed on the beds at the EMWC. Four blocks of each subject were laid out on each bed. Each block consisted of 45 plants, arranged in 5 columns of 9 plants, with columns staggered and 3 cm spaces left between pots. Blocks were arranged in three columns of four; the location of each subject was randomly selected. Within each block, 10 plants were randomly selected for monitoring purposes. Their growth was monitored (heights and widths in perpendicular directions were measured when the plants were placed on the beds and again in September and in November) over the season and quality was assessed at the end of the season. Root quality was reassessed in February 2007, and shoot quality for *Cistus* (the only one of the shrubs with leaves at this time) was also reassessed. In March 2007 a rapid assessment (one measurement per block) of shoot quality was undertaken, before removing these plants from the beds to make way for a new crop. This new crop consisted of *Cistus* x *pulverulentus* "Sunset", *Potentilla fruticosa* "Tangerine", and *Spiraea japonica* "Shirobana", in the same layout as the previous year. They were placed on the beds in April. Plant height, width, and quality of both the shoots and roots were assessed 20th to 24th August. For quality, plants were classified into three groups, class 1 to class 3. For shoot quality, class 1 plants were those with good coverage of the pot, even heights of stems, not too many gaps when looked at from the side, and healthy foliage. A class 3 plant might have an uneven shape or some areas with little foliage. A class 2 plant was intermediate between these. Roots were considered to fall into class 1 root quality where roots could be seen over the whole of the compost sides, and the roots reached the base of the pot (examples in Fig. 11). A class 3 root system was a system where roots were patchy or missing from part of the sides of the compost or did not reach the base. A class 2 root system was intermediate between these (examples in Fig. 12).

<u>Monitoring of water application, run-off, substrate moisture and meteorological conditions</u>

The quantity of water applied to each bed was monitored with a water meter. These meters were connected to data-loggers (Delta-T Devices Ltd.) for continuous recording of water use. Run-off (water applied to the beds that drains through and is collected at the end of the beds) was captured for Beds A and B in containers in the culvert into which these beds drain separately. Measurement of run-off indicates how much of the water applied is wasted either through missing the pots or draining through the pots. Run-off is measured every day. In 2006 run-off was measured in large calibrated containers, but these were sometimes insufficiently large to contain all the run-off after heavy rain or substantial irrigation, so in 2007 tipping buckets with counters were used instead (Figure 13).

The accumulated degree hours from 8 am one day to 8 am the next was recorded 7 days a week. Meteorological data was continuously recorded on the EMWC – this includes rainfall, air temperature, relative humidity, and solar radiation amongst other measurements. The GP1 logger records moisture in the compost of the “control” pot i.e. the pot with the moisture sensor that is used to determine whether or not irrigation is required. It additionally records moisture in a second pot. Other soil sensors (Thetaprobes, Delta-T Devices Ltd.) were used in 2006 to monitor moisture in a wider selection of pots – one of each species on Bed D and one pot on each bed A, B, C and F. To determine variability within beds, moisture was measured in the pots of each of the selected plants (i.e. 120 plants per bed) monthly from July to September in both 2006 and 2007.

Figure 11. Examples of different classes of quality of *Potentilla* (left) and (right) shoots from top quality (1, top photos) to unacceptably poor quality (3, bottom photos).

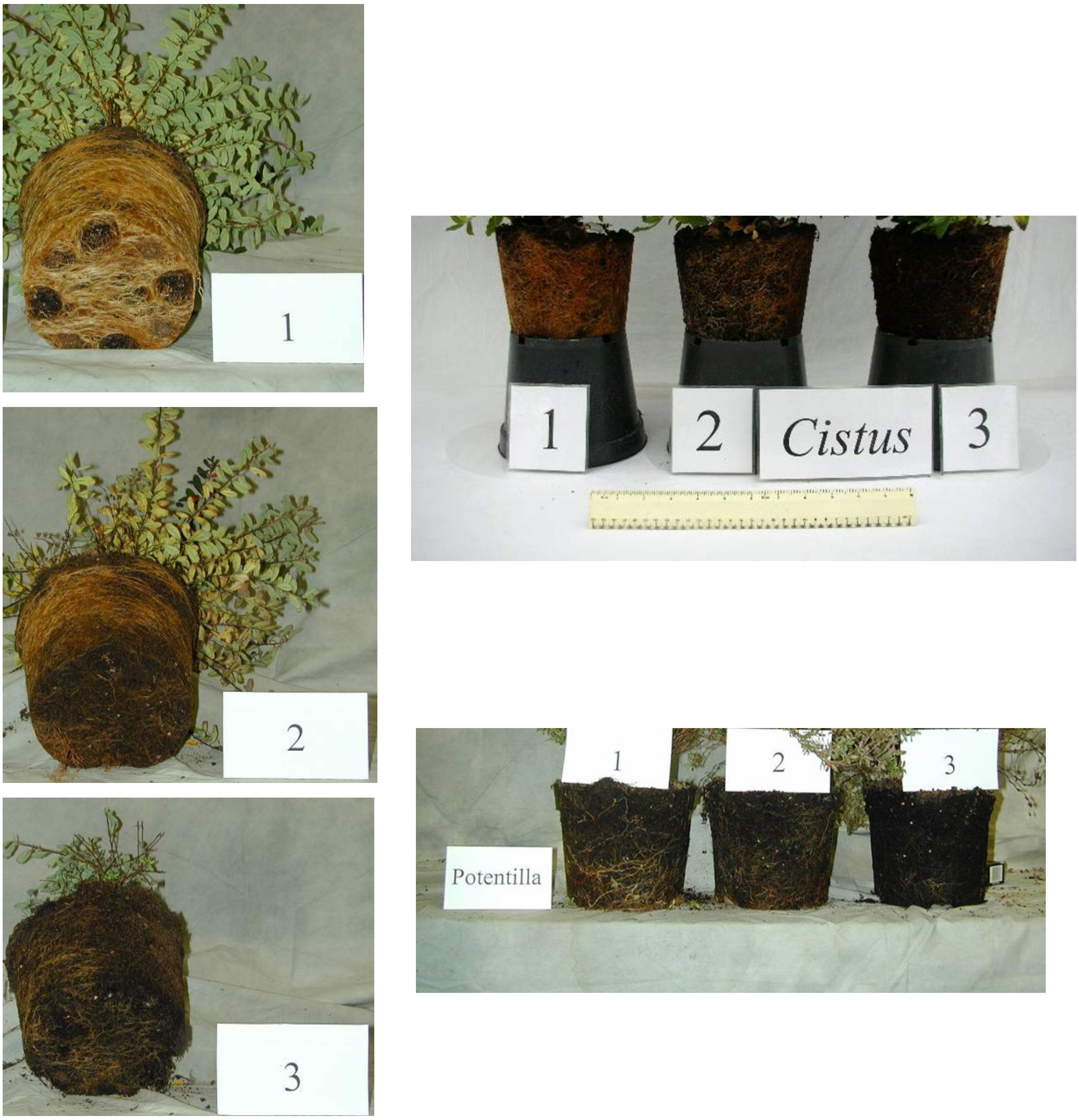

Figure 12. Examples of different classes of quality of *Spiraea* (left), *Cistus* (top right), and *Potentialla* (bottom right) roots from top quality (1) through intermediate (2), to unacceptably poor quality (3).

Comparisons between nurseries and between beds on nurseries carried out in WUMS also provide indications of the value of different irrigation systems in terms of saving water.

Figure 13. Tipping buckets used to monitor run-off from beds. Tips of the buckets were automatically recorded and the total number of tips read daily. This was then converted to litres of water.

Objective 4. Deliver technology transfer activities including grower visits to the EMWC.

This project has contributed to HDC factsheets on irrigation, in particular Factsheet 16/05 "Measuring and improving performance of overhead irrigation for container-grown crops". Various grower groups have benefited from visits to the EMWC. In particular, the 2007 crop, and the beds, sprinklers, sensors etc. in use were demonstrated to HDC levy payers during the HDC Irrigation Day on 11th September 2007 (Figure 14). Other visitors include:

HDC HNS Panel visit 13th September 2005

EMR Open Trade Day 22nd September 2005

HDC HNS Panel visit 7th June 2006

West Sussex Fruit Growers visit 18th July 2006

Kent Ambassadors visit 20th July 2006

Fruit Focus 26th July 2006

HDC HNS Panel visit 6th December 2006

Nuffield Scholar visit 12th July 2007

British Ornamental Plant Association 17th July 2007

SEEDA visit 26th July 2007

Kent Horticultural Discussion Group, 31st July 2007,

and visits from individual growers, consultants etc.

In addition, results obtained both on the EMWC and on nurseries in this project were described at that event. Work being undertaken both on the EMWC and on commercial nurseries were described in HDC News articles in 2006 and 2007.

Figure 17. Growers being shown around the EMWC during the HDC Irrigation Open Day 11th September 2007.

Results

EMWC

<u>Performance of irrigation systems</u>

The distribution of irrigation over a bed varied greatly according to how still or windy the weather (example for MP2000s in Figure 15). The distribution also differed between systems. As expected, a more uniform distribution was found on beds with MP2000 sprinklers than on the bed with rotoframes (Bed F) (Figure 16 and Table 4). Mean application rate is more difficult to calculate for the gantry, since in a run that lasts say 7 mins, water will only be over any one plant for a small fraction of this time. The application rate over a given plant is very high with our gantry when a slow speed is used. Even at the faster speeds, application rate is quite high relative to the conventional overhead irrigation systems in use on the EMWC (Figure 17a). Plants were weighed before and after irrigation at several different speeds in order to determine water uptake at different speeds. Uptake at all other speeds was extrapolated from these data (Figure 17b).

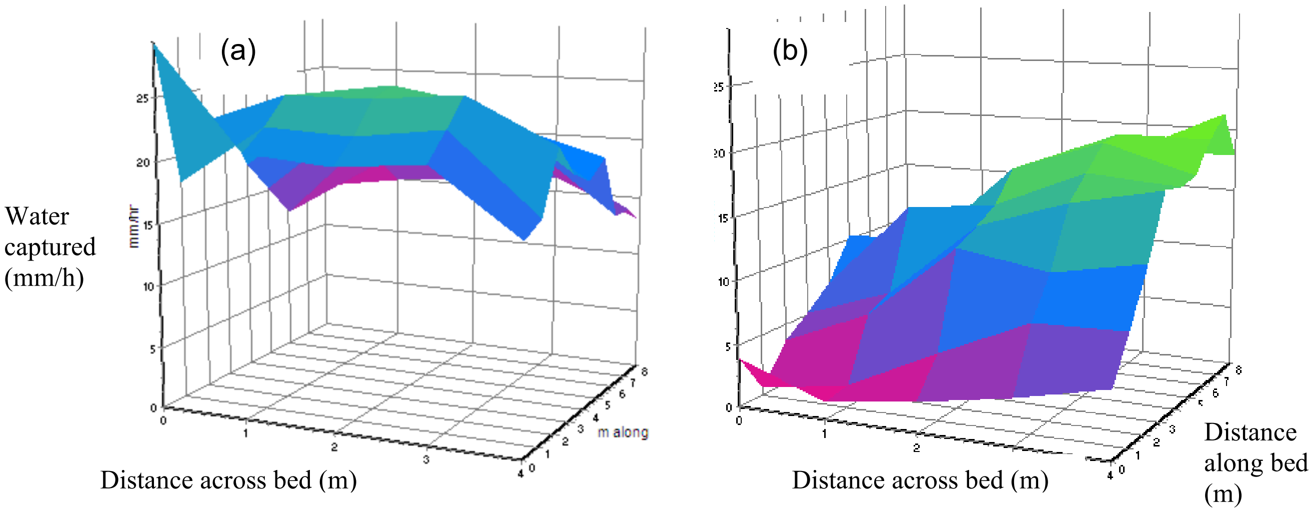

Figure 15. Distribution of irrigation water captured in saucers on a bed irrigated with MP2000 sprinklers (Beds A, B and D) spaced at 2.5 m between sprinklers along the laterals of the bed and 5 m between the laterals, on (a) a still day and (b) a windy day.

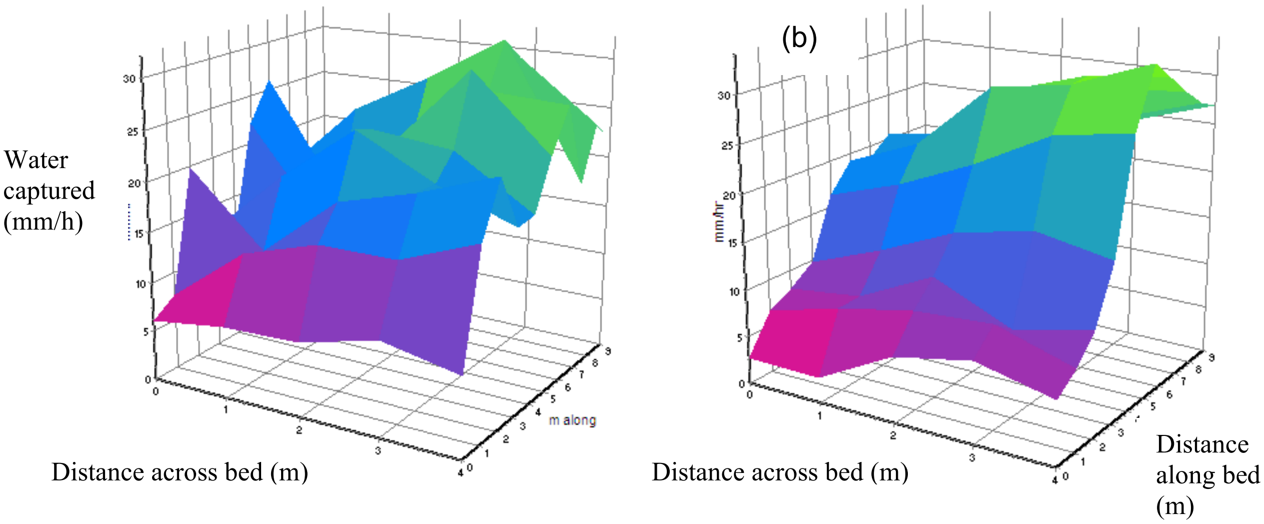

Figure 16. Comparison of the distribution of irrigation water captured in saucers under MP2000 Rotators (a), and under Rotoframe sprinklers spaced at 5 m between sprinklers and sprinklers placed 2.5 m in from the edges of the 5 m x 10 m bed (b). Measurements were taken on 26th March 2007, a breezy day.

Table 4. The best recorded irrigation performance of MP2000 and rotoframe sprinklers and gantry sprinklers on the EMWC, where MAR is mean application rate, CU is Christiansen's Coefficient of Uniformity, SC is the scheduling coefficient, and $SC_{5\%}$ is the scheduling

coefficient when the MAR is divided by the 5th percentile value rather than the lowest catch.

Performance	Sprinkler		
	MP2000s	Rotoframes	Gantry
MAR (mm/h)	19.9	14.4	n.a.
CU (%)	83	64	95
SC (%)	1.6	3.0	1.2
$SC_{5\%}$ (%)	1.5	2.2	1.1

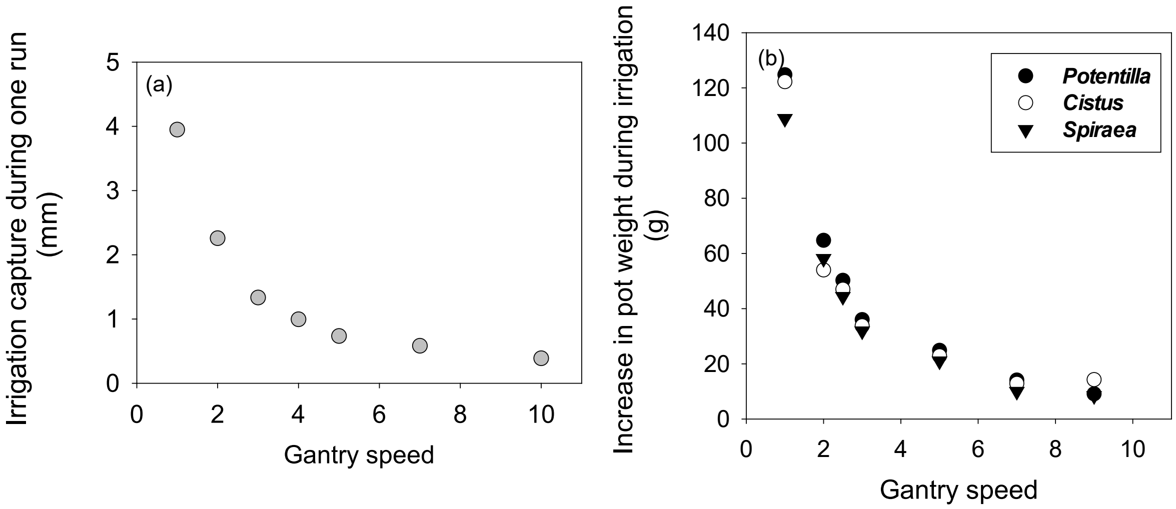

Figure 17. Irrigation output captured in saucers at different speeds of the gantry on the EMWC (a), and the resulting increase in weight of pots of three species under those different speeds (b).

<u>Scheduling</u>

Air temperature and relative humidity varied over the season and, as a result, daily accumulated total degree hours varied considerably between dates (Figures 18-19). High values of daily accumulated degree hours were apparent on dates when the temperature was high and the relative humidity was relatively low. The length of irrigation run on a given date was determined from the accumulated degree hours from 8 am the previous morning to 8 am that day. The length of the irrigation run relative to the accumulated degree hours changes over the season because as the plants grow they need more water per degree hour i.e. the calibration factor increases. In 2006 plants on Mypex increased their weight by 22% more than plants on gravel under a comparable system after irrigation. Therefore less water was applied to this bed later in the season in 2006. In 2007 separate calibrations were performed for use of the Evaposensor with gravel and with Mypex beds.

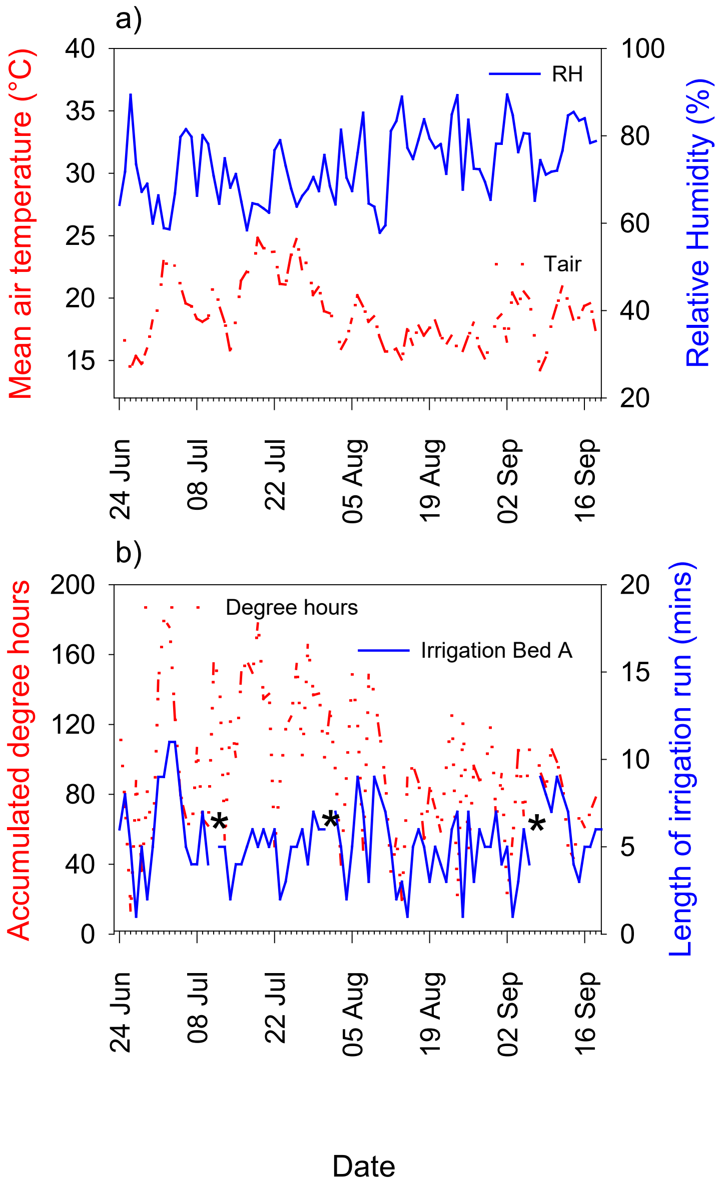

Figure 18. Mean daily air temperature and relative humidity (a) and daily accumulated degree hours, along with the length of irrigation runs used on Bed A (gravel, MP2000s, Evaposensor) on different dates (b), for 2006. Irrigation was applied four times a day. The arrows indicate dates on which irrigation was not applied because the calibration was being undertaken. On a few dates irrigation was turned off due to rainfall.

Irrigation water use

Less water was used on the Mypex bed than on the gravel bed with the same scheduling method (Evaposensor) and irrigation system (MP2000s) in both years (Figures 20-21). The difference is more noticeable in 2007 (the Mypex bed used 70% of the irrigation water used on the comparable gravel bed in 2007, whereas in 2006 the Mypex bed used 82% of that on the comparable gravel bed), because in 2007 a different calibration was used for the Mypex and gravel beds throughout, whereas in 2006 a different calibration was only applied for part of the season. The Mypex drained more slowly and so plants could take up more water during and after irrigation than on the gravel bed.

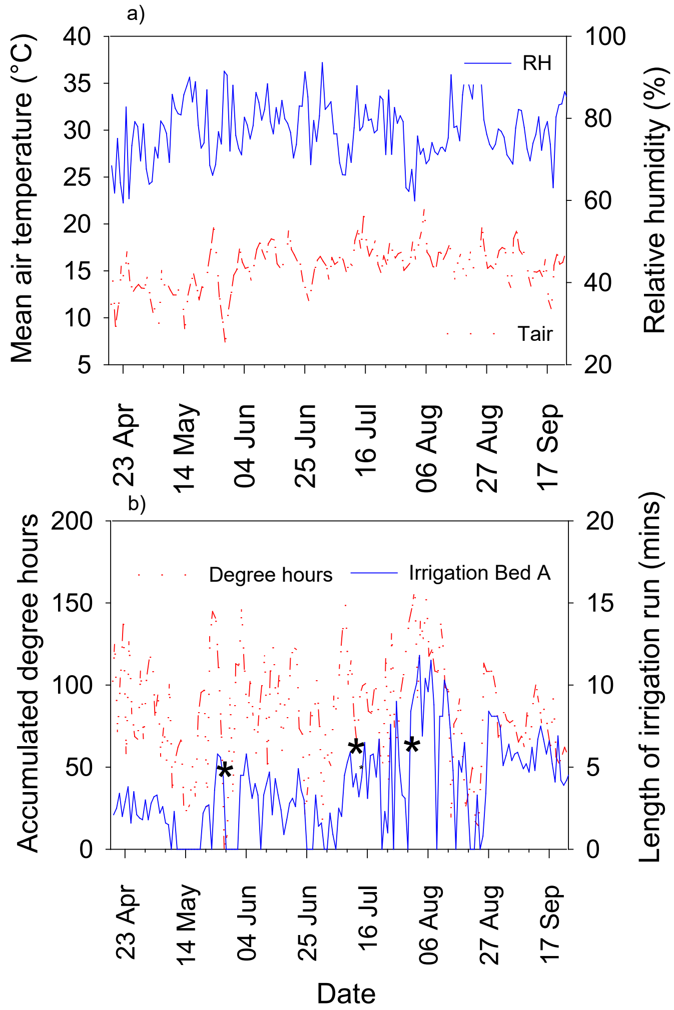

Figure 19. Mean daily air temperature and relative humidity on the EMWC during the growing season of 2007 (a), and the corresponding accumulated degree hours and the length of irrigation runs on Bed A (gravel, MP2000s, Evaposensor (b). Irrigation was applied four times a day, as the previous year. In 2007, rainfall was measured daily and taken into the calculations of irrigation requirements; thus the irrigation runs on some days (after rainfall) are shorter relative to the accumulative degree hours than on others. After substantial rainfall no irrigation was applied. The arrows indicate when new calibrations were undertaken.

On several days when irrigation was applied to beds scheduled with the Evaposensor, the irrigation did not turn on on the bed scheduled with the soil sensor, as the substrate was already sufficiently wet. However, irrigation runs on the soil sensor bed of 15 mins were longer than generally used on the Evaposensor beds (average of 4 mins on the comparable Evaposensor, gravel, MP2000s bed in 2007). On average, 3% of irrigation ran through pots during 15 min irrigation runs, compared to only 0.7% during 8 min irrigation runs, and no run through occurred during 3 min irrigation runs. The longer irrigation run on the soil-sensor bed may therefore have contributed to some wastage of water, but a reasonable length of run is required to ensure sufficient application of water with the soil sensor system. Despite this possible source of wastage, less water was used with the soil sensor system than on the Evaposensor-scheduled MP2000s gravel bed. This was the case both in the dry summer of

2006 and the wet summer of 2007. Lowering the threshold at which irrigation stayed off with the soil sensor in 2007 probably saved water, but in 2007 water use on the bed scheduled with the soil sensor was 84% of that on the comparable Evaposensor bed, whereas in 2006 it was 73%. There was probably less difference between the two systems in 2007 because we improved our scheduling on the Evaposensor bed: rainfall in 2007 was measured and taken into account when calculating the quantity of water still required to replace evapotranspiration.

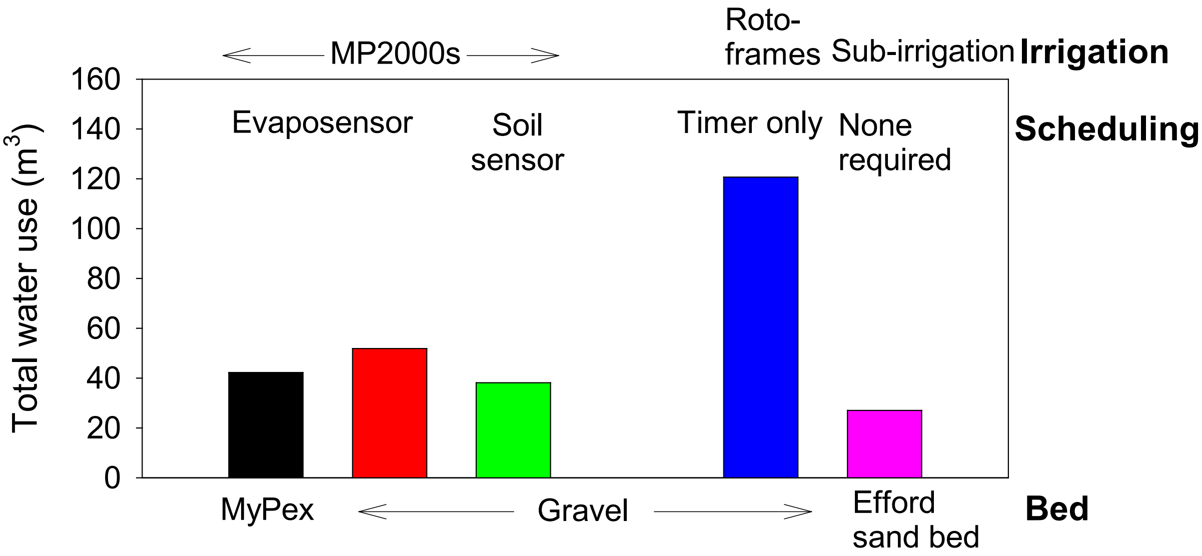

Figure 20. Irrigation water use on 10 m x 5 m nursery stock beds from 28/06/06 to 31/10/06. Different types of beds (Mypex, gravel, Efford sand bed), different methods of applying irrigation (MP2000s, rotoframes, sub-irrigation), and different methods of scheduling irrigation (Evaposensor, soil sensor, timer only) were compared.

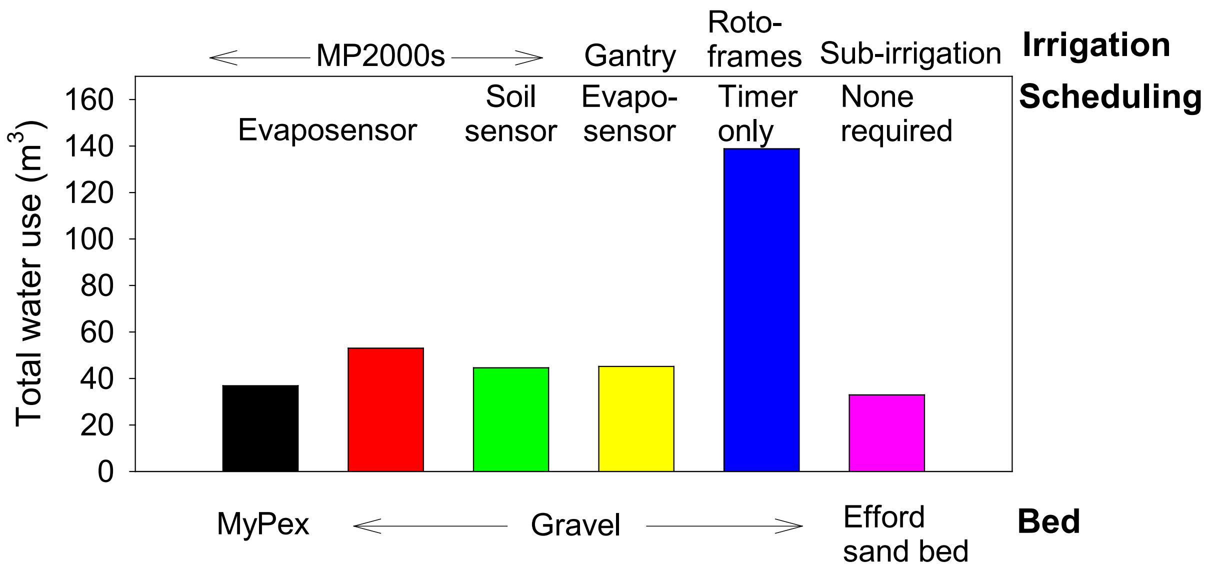

Figure 21. Irrigation water use on 10 m x 5 m nursery stock beds from 04/05/07 to 23/09/07. Different types of beds (Mypex, gravel, Efford sand bed), different methods of applying irrigation (MP2000s, gantry, rotoframes, sub-irrigation), and different methods of scheduling irrigation (Evaposensor, soil sensor, timer only) were compared.

Total irrigation water use over the summer of 2007 was less (85%) when a gantry was used compared with when a conventional overhead irrigation system with the same method of scheduling (the Evaposensor) was used. Water use with the gantry was comparable to that used with conventional overhead irrigation and the soil moisture sensor.

Comparing the gravel beds with conventional overhead irrigation, substantial savings of water were made by using MP2000s and scheduling compared to rotoframes without scheduling. In both years, water use on the rotoframe, unscheduled, bed was more than twice that on the Evaposensor-scheduled MP2000s bed and more than three times that on the soil-sensor scheduled MP2000s bed. These differences relate partly to the high scheduling coefficient on the rotoframes bed, and partly to the absence of scheduling.

The Efford sand bed used approximately 70% of the irrigation water used on the gravel bed scheduled with the soil moisture sensor (the next most efficient bed). Hourly data indicated that the Efford bed used water in small quantities but almost continuously.

Run-off was frequently greater from the gravel bed than from the Mypex bed (Figure 22) on account of greater quantities of irrigation being applied to the gravel bed. The combination of rainfall and irrigation in some cases led to far greater quantities of water running off the beds than were applied as irrigation. It should be noted that on EMWC beds there were spaces between blocks to allow movement around plants for measurement of substrate moisture, plant growth etc. Therefore a considerable amount of irrigation and rain water will have fallen on bare gravel/Mypex rather than on plants. For this reason our run-off values are likely to be higher than those from a similarly sized bed on a nursery. In general there was more run-off during times of longer irrigation runs than early in the season when the plants were small and their irrigation demand was less.

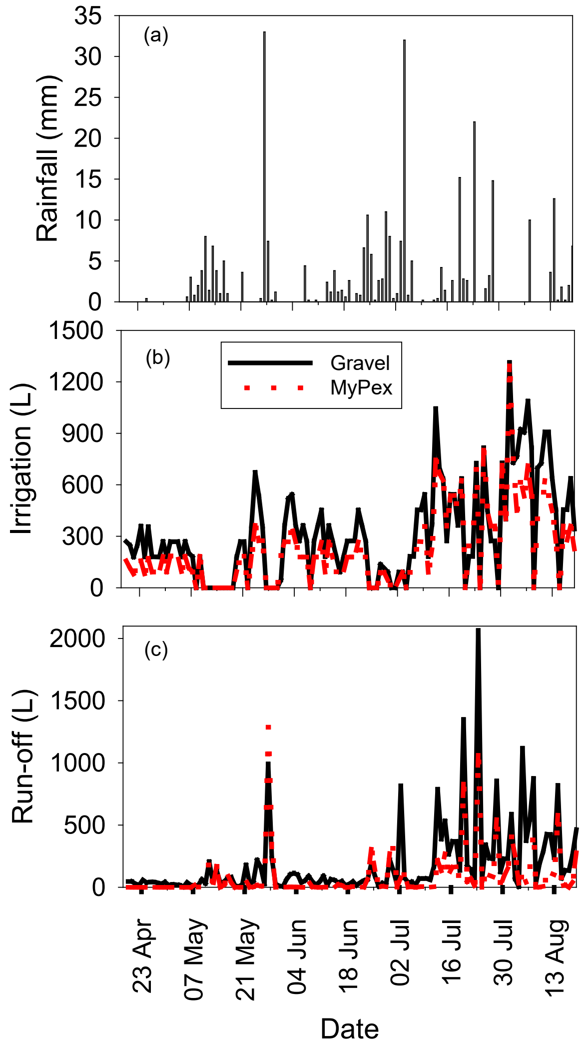

Figure 22. Rainfall (a) and quantity of irrigation water applied to Beds A (gravel) and B (Mypex) on different dates (b) and the quantity of run-off water collected from either bed (c).

<u>Substrate moisture content</u>

Volumetric moisture of the substrate (measured at about 6 cm depth in the pot) varied within and between beds and over time (example in Figure 23). In July 2006, substrate moisture on the gravel bed with MP2000s and Evaposensor-scheduling was on average quite low. This may relate to substantial growth between calibration of degree hours against water use and the substrate moisture measurements; when the calibration was repeated the distribution of substrate moisture on this bed centered around 35-40%. By September 2006, however, a very wide spread of substrate moistures was found on this bed (from 10% to 90%), probably relating to the accumulated effect of a non-uniform distribution on an overhead-irrigated bed. Substrate moisture on the Mypex bed was higher than on the corresponding gravel bed in July and August, as a result of water being retained on the Mypex and distributed to the plants. The calibration factor was then reduced on this bed compared to the gravel bed, but nonetheless substrate moisture was still generally very high on this bed in September. This may relate partly to rainfall, which would be expected to have more of an effect on the Mypex bed than on gravel beds. Pots on the Efford sand bed showed a fairly uniform distribution of substrate moisture in July, with most pots having substrate moistures between 20 and 40%. Substrate moistures on the Efford sand bed were less uniform in August, but by September most pots had substrate moistures of between 35 and 55%, with just a few pots with lower substrate moisture – these were pots in which either a good contact with the sand or a substantial root system was not established early on in the season. Substrate moisture on the soil-sensor scheduled bed was very similar to that on the Efford sand bed in July and August, but was generally very low in September. This shows the danger of scheduling a bed based on the substrate moisture in one pot: the sensor was in the middle of the bed in one of the relatively few pots with substrate moisture above 35%, meaning that irrigation did not turn on even though most of the pots on the bed had much lower substrate moisture.

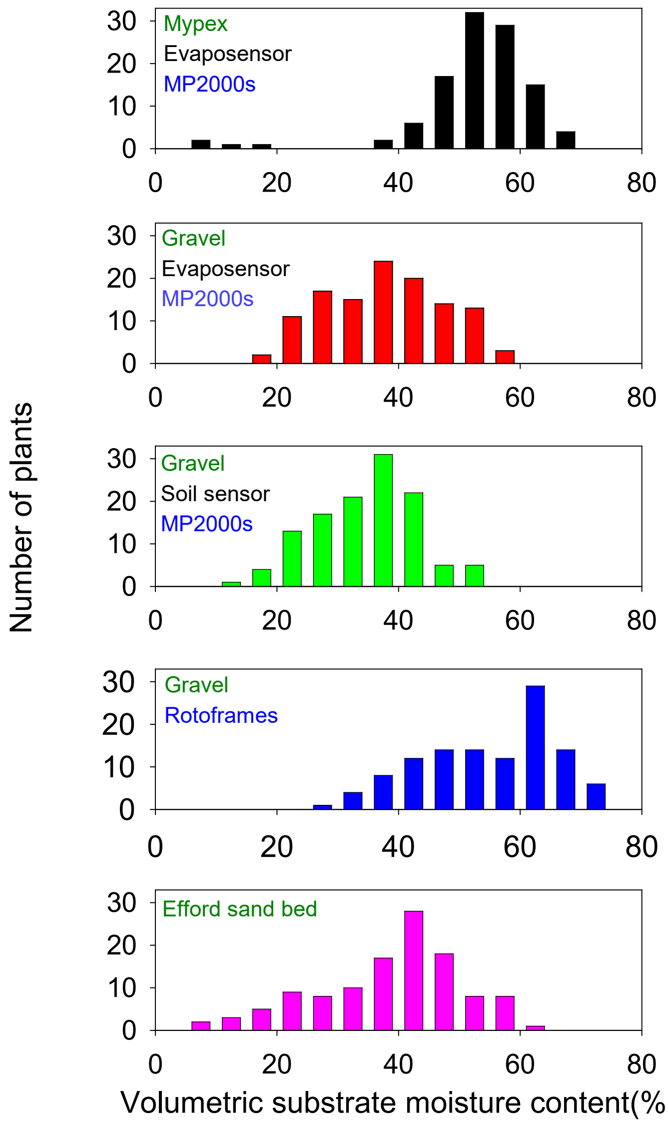

Figure 23. Numbers of pots on each bed with volumetric compost moisture falling between 5% categories from 5% to 90% compost moisture, measured on 16th August 2006. Approximately 120 pots were measured per bed (40 plants per species).

In 2007, a very high percentage of plants on the Efford bed had quite dry substrates, often with lower than 20% volumetric substrate contents (Figure 24). Substrate moisture content in pots on the soil sensor bed was generally between 35 and 55% in July, but had fallen considerably for a number of pots on this bed by August. This might relate to possibly faster growth rates and hence greater water use in some of the plants than were occurring in the plant in the pot of which the controlling sensor was placed. A wide range of substrate moistures was seen in pots on the gravel MP2000s bed scheduled with the Evaposensor, though the distribution of substrate moistures on this bed became more uniform by August. Conversely, the distribution of substrate moisture under the gantry became more scattered by August. Some pots on the gantry, rotoframes, and Mypex beds were quite wet in both months; this may relate partly to rainfall, but cannot relate entirely to rainfall given that several pots measured at the same time on other beds were quite dry.

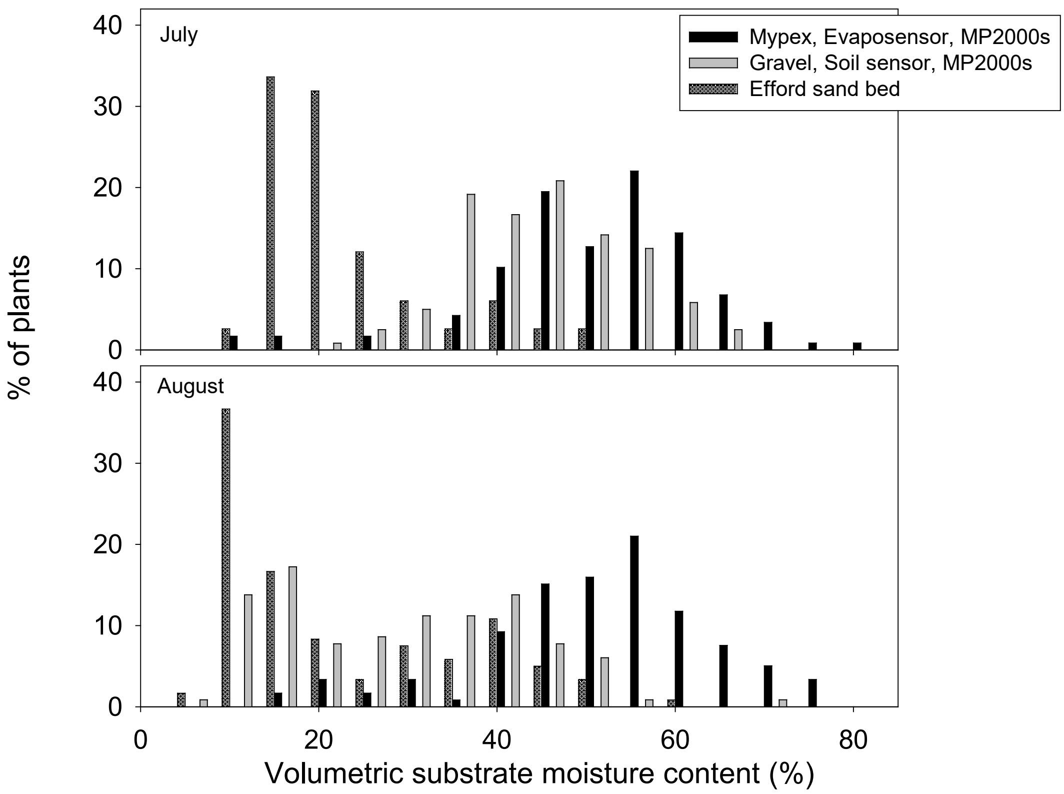

Figure 24. Percentage of plants on each bed with volumetric substrate moisture in each 5% category (6-10%, 11-15% etc.) in July (top graph) and August (bottom graph) 2007 for three different types of beds.

<u>Plant growth</u>

Both years, plants grew substantially over the season on all beds. In 2006, by September the *Cistus* were tallest on the Mypex bed and Efford sand bed, and shortest on the gravel MP2000s bed scheduled with the Evaposensor (Figure 25). They also showed relatively little outward growth on the latter bed. *Potentilla* were also shortest on the gravel MP2000s bed scheduled with the Evaposensor but on the same bed were relatively wide. *Spiraea* grew tallest on the Efford sand bed and widest on the Mypex bed. In general therefore it is difficult to conclude that plants were smallest or largest on any one bed, but *Cistus* grew least on the gravel MP2000s bed scheduled with the Evaposensor and most on the Efford sand bed, *Spiraea* grew tallest on the Mypex bed but widest on the gravel MP2000s bed scheduled with the Evaposensor, and grew least on the Efford sand bed, and *Potentilla* grew most overall on the Mypex bed. By November, however, plants of all three species were significantly taller on the Efford bed than any of the other beds.

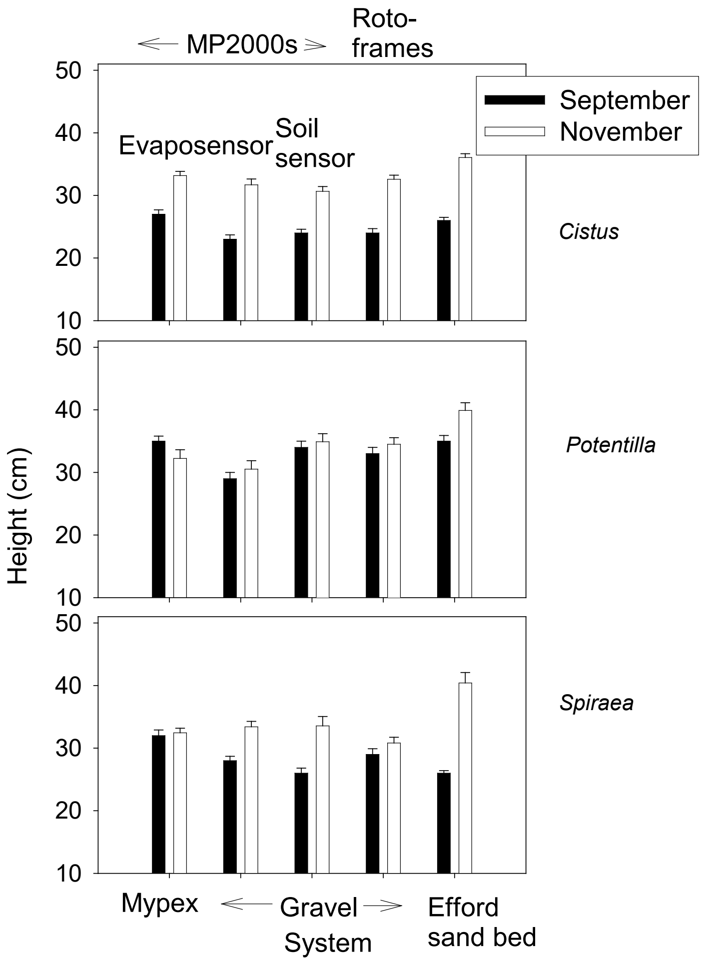

Figure 25. Plant heights measured on 11th September and 14th November 2006 on the EMWC.

In 2007, significant differences in plant sizes (both height and width) were again found between beds ($P < 0.001$), when measured at the end of August (Figure 26). *Cistus* were tallest on the Efford sand bed and the Mypex bed and shortest under the rotoframes. *Potentilla* were tallest on the Efford sandbed and S*piraea* were tallest on the Efford sand bed and MyPex bed. Both *Cistus* and *Potentilla* were wider on the Efford sand bed than on other beds.

In 2006, by November, better shoot quality was found on the subirrigated Efford sand bed and the GP1-scheduled gravel bed than on the other beds. For *Cistus* and *Spiraea* no plants on these beds fell into the poor quality category (Figure 27). A high proportion of *Cistus* and *Potentilla* on the rotoframes bed fell into the poor quality category while for *Cistus* in particular, a high proportion (88%) of plants on the Efford sand bed and soil sensor bed fell into the best quality category. In February, only the *Cistus* were scored for shoot quality, since the others have no leaves at this time of year. They were again found to show higher quality on the Efford sand bed and GP1 scheduled bed than on the other beds. A rapid survey of overall shoot quality in each block of plants late in March, when *Spiraea* was starting to produce new leaves, indicated little difference in quality between beds, with the exception of some poorer quality plants on the rotoframes bed.

In November, the best root quality was found on the subirrigated Efford sandbed. The worst apparent root quality at this stage was found on the GP1-scheduled bed. It is interesting that plants on this latter bed had such good quality above the substrate but relatively poor quality roots, which might affect establishment or shelf life. However, in February, by which stage drainage over winter would be expected to have influenced root quality, the quality of the root systems on this bed was no different than on any other save the Efford sand bed. For all three species, the Efford sand bed stood out as producing top-quality root systems. For *Cistus*, root quality on all the other beds was similar at this stage. For *Potentilla*, the two beds scheduled with the Evaposensor showed the worst quality at this stage, whereas for *Spiraea*, the lowest quality root systems were found with plants on the Mypex bed and the plants that had been irrigated under the Rotoframes (on gravel). This highlights how the same bed or irrigation system can be optimal for one species or cultivar but not for another.

Mosses and liverworts did not occur on the subirrigated Efford sand bed. Mosses and liverworts were most abundant on the Mypex bed and under the rotoframes, indicating that at times the upper layers of substrate in pots on these beds were wet enough to encourage moss/liverwort establishment.

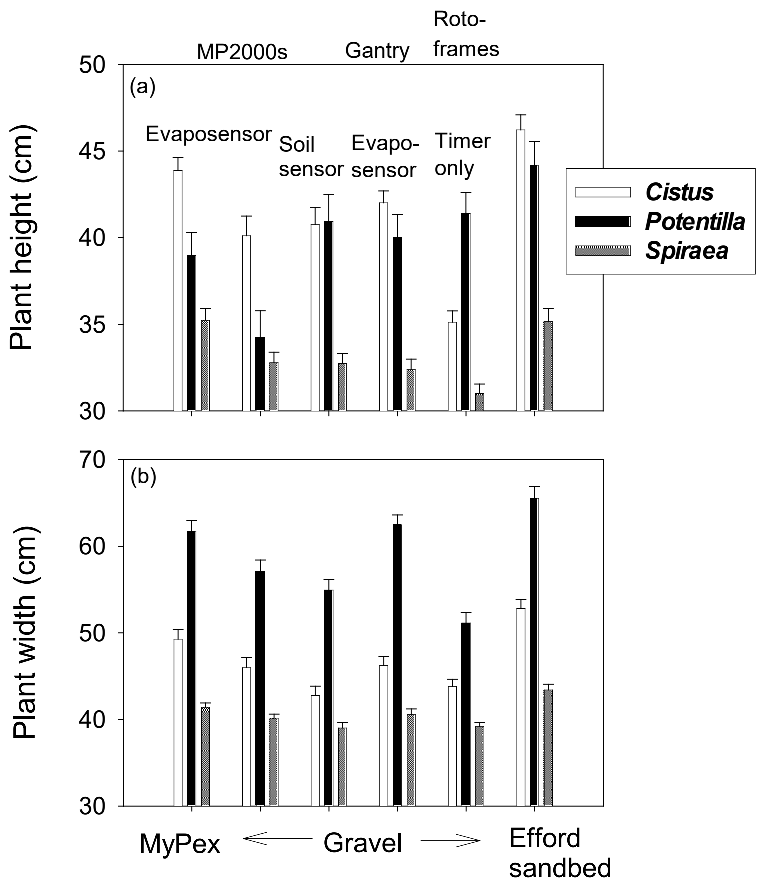

Figure 26. Plant heights (a) and widths (b) measured 23rd August 2007 on the EMWC.

In 2007, there were again significant differences between beds in both shoot quality and root quality (***P*** < 0.001), this time measured late August. However, patterns of quality across beds were very dependent on species. For ***Cistus,*** the best shoot quality was found under the rotoframes, and the worst on the Mypex bed. For ***Potentilla***, the best shoot quality was found on the Efford sandbed, with 75% percentage of plants on that bed falling into the best quality category (Figure 28) and the worst on the Mypex bed. For ***Spiraea***, shoot quality was best on the Efford sand bed and on the soil sensor scheduled bed, and worst on the Evaposensor-scheduled MP2000s gravel bed. The best root quality for ***Cistus*** was found on the rotoframes and Evaposensor-scheduled MP2000s gravel bed. The best root quality for ***Potentilla*** however was on the gantry bed. However, "best" and "worst" are perhaps misleading terms here, as in fact very few plants of any species on any bed fell into the poor quality category (Figure 29).

The greatest variation in plant height for ***Cistus*** and ***Potentilla*** occurred on Bed A (the gravel bed with MP2000s and scheduled with the Evaposensor) two years in a row. For ***Cistus***, the greatest variation in plant width also occurred on this bed two years in a row. The greatest uniformity of plant height for ***Potentilla*** occurred on the Efford sand bed in both 2006 and 2007. ***Spiraea*** showed the greatest variation in plant width on the soil sensor bed two years in a row. The greatest uniformity of root quality occurred on the Mypex bed for *Cistus* and *Spiraea* in 2006, but this was not seen in 2007. The greatest uniformity of plant widths occurred on the rotoframes bed in 2007, but for height, uniformity on different beds was dependent on the species: the greatest uniformity of plant heights occurred on the gantry bed for *Cistus*, on the Efford sand bed for *Potentilla*, and on the rotoframes bed for *Spiraea*. In 2007 the most uniform shoot quality occurred on the gantry bed for *Cistus* and *Spiraea*, but shoot quality of *Potentilla* was most uniform on the Mypex bed. In 2007 the most uniform root quality for *Cistus* and *Potentilla* occurred on the Efford sand bed, but for *Spiraea* the most uniform root quality occurred on the soil sensor scheduled bed.

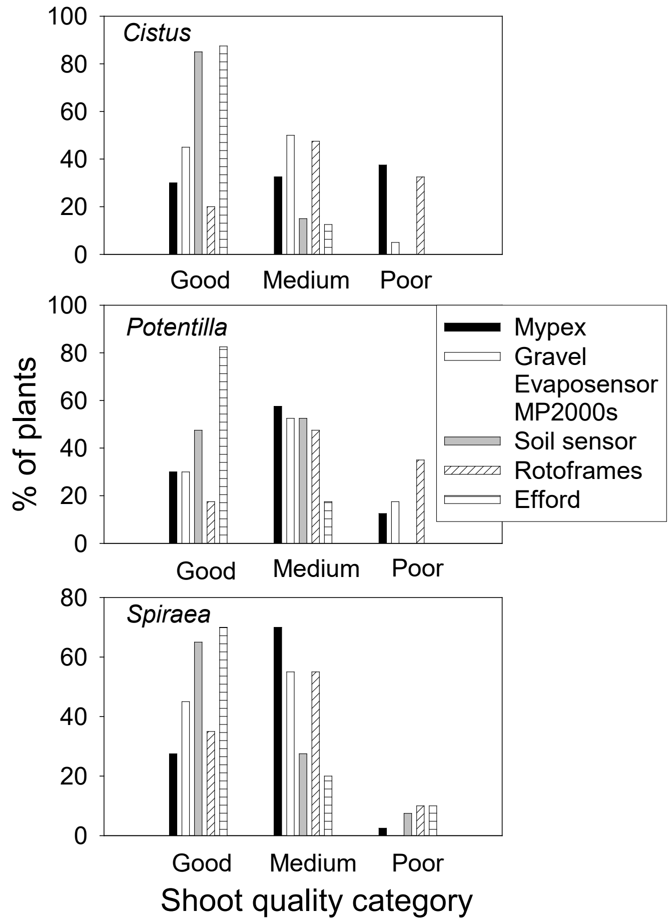

Figure 27. Percentage of plants on each bed falling into each of three quality categories with respect to shoots in November 2006.

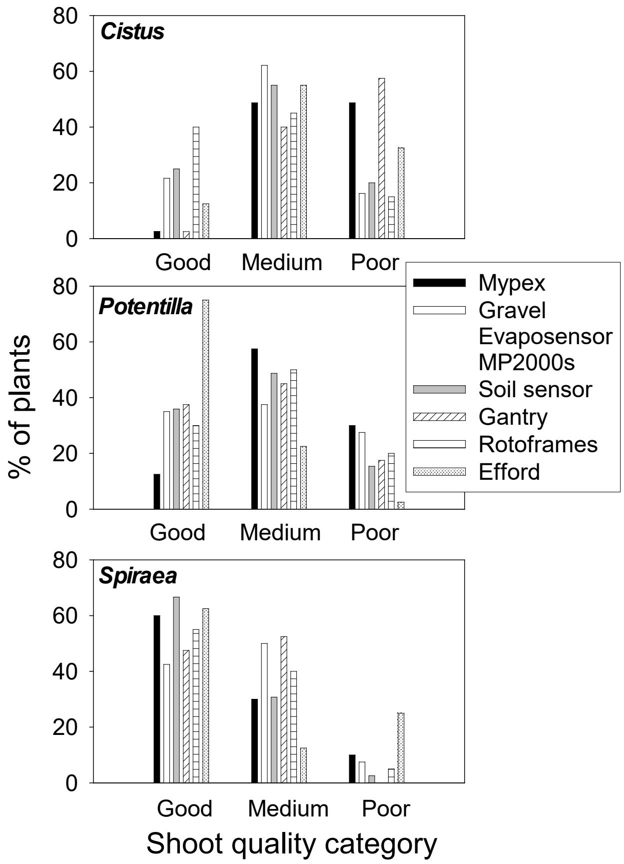

Figure 28. Percentage of plants on each bed falling into each of three quality categories with respect to shoots in August 2007.

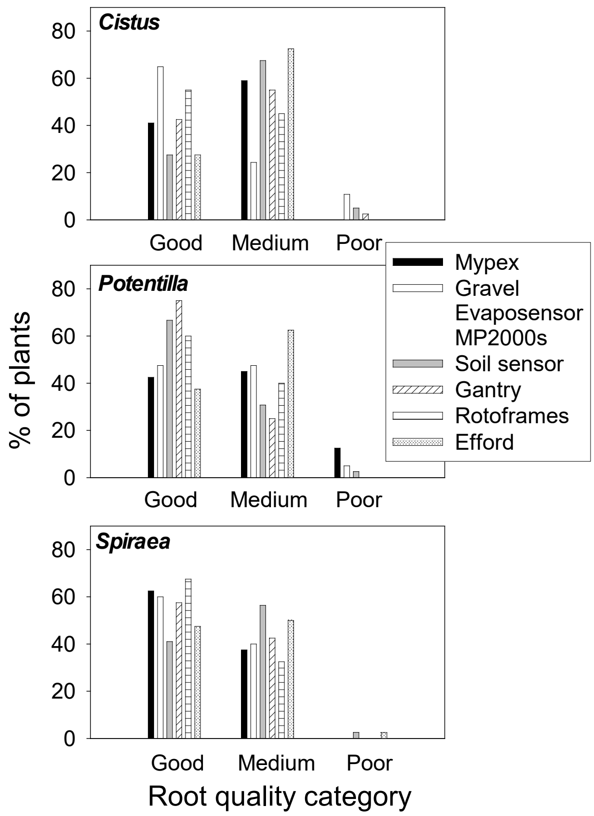

Figure 29. Percentage of plants on each bed falling into each of three quality categories with respect to roots in August 2007.

WUMS

Performance of different irrigation systems

There was a large variation in the amount of irrigation applied, both between different nurseries, and between different bed treatments within a nursery. For example at the Yorkshire nursery, in 2006 the Mamkad sprinkler bed averaged 6 mm/day compared to 2 mm/day for the MP Rotator sprinkler bed. In this case the large differences were partly accounted for by the different crops placed on the beds as well as the different sprinklers used. A *Viburnum* crop grew more slowly and required less water than some vigorous grasses on the Mamkad bed, where higher output impact sprinklers were installed on part of one line to apply more water to the grass crop portion of the bed. Comparative uniformity data were not available from this site in 2006, so it is not clear how differences between the two beds here might account for some of the water consumption differences. All irrigation quantities in mm in WUMS were calculated on a 'bed area' basis – i.e. litres applied per m^2 of bed area. This is more meaningful for comparing irrigation "efficiencies" between sites, though will slightly overestimate the actual mean precipitation reaching the crop where there is significant overspill beyond the bed area. In most cases here the differences were less than 20% between the irrigation calculated on a "bed area" compared to "irrigated area" basis.

At the Norfolk nursery, a similar crop (*Sambucus*) was grown on two different bed areas in 2006, using the same type of impact sprinklers, but at two different densities. Following a rather poor distribution pattern measured in a different area used for the 2005 trial, the nursery decided to try the sprinklers in a closer spaced arrangement in 2006 (Figure 30). Water use was relatively high (compared to other nurseries) from both arrangements in 2006, averaging about 5 mm/day for both spacings. The nursery reported that hot, dry and breezy conditions, particularly in late June and July, resulted in pots drying out and many blowing over, and requiring particularly heavy irrigations to re-wet them. However, the data showed that substantial irrigations were being applied on most days over this period. Figure 30 shows the results from a distribution test on their close-spaced sprinkler arrangement using the HDC Irrigation Calculator. Irrigation uniformity was still relatively poor (CU 73%; $SC_{5\%}$ 1.8), and this would also have contributed to relatively high water consumption.

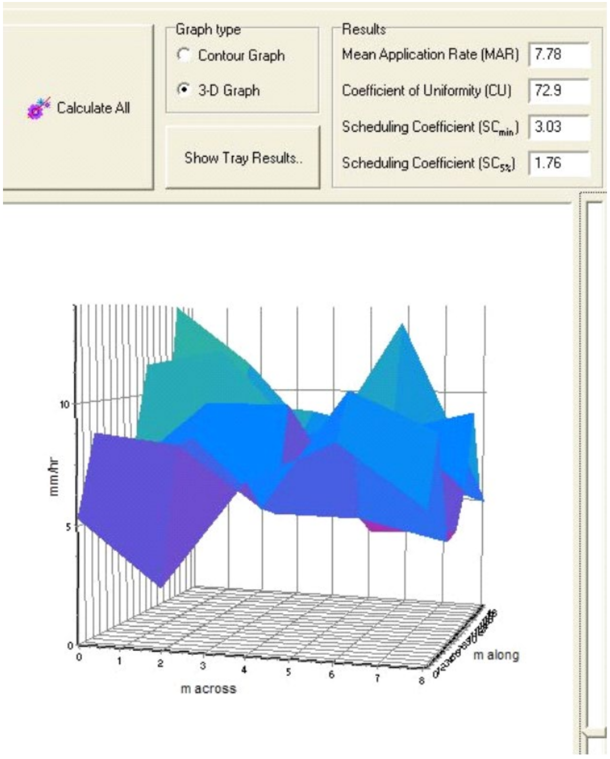

Figure 30. Results from an irrigation distribution test from Norfolk nursery close-spaced sprinkler treatment.

Irrigation in relation to environmental conditions

Environmental conditions varied between sites and over time (example in Figure 31). Higher accumulated degree hours and lower rainfall would be expected to lead to greater demand for water. Note that none of the growers scheduled irrigation according to the Evaposensor degree hours, but nonetheless there is a general trend to apply more irrigation (Figure 31c) when the evaporative demand was high (a large total of degree hours in a week, Figure 31a) and rainfall was low (Figure 31b), though there are some anomalies to this trend.

Scheduling of irrigation

The nursery in Surrey is a herbaceous nursery. Each year, water use was lowest on this nursery (Table 5 summarises the average water use on all nurseries each year). In 2005, it was assumed that the type of crop (fairly small herbaceous subjects in 9 cm pots) was largely responsible for the low water use, although irrigation distribution tests did show good uniformity from the sprinkler system employed. In 2006, however, the *Penstemon* in 2 L containers were quite tall and leafy, and arguably required as much water as some of the subjects grown by other nurseries. However water consumption was still relatively low. It is likely that the use of an irrigation scheduling method (in this case a crude but effective 'bucket evaporimeter' as described in HNS 38) has provided a good guide to irrigation need, and has avoided over application.

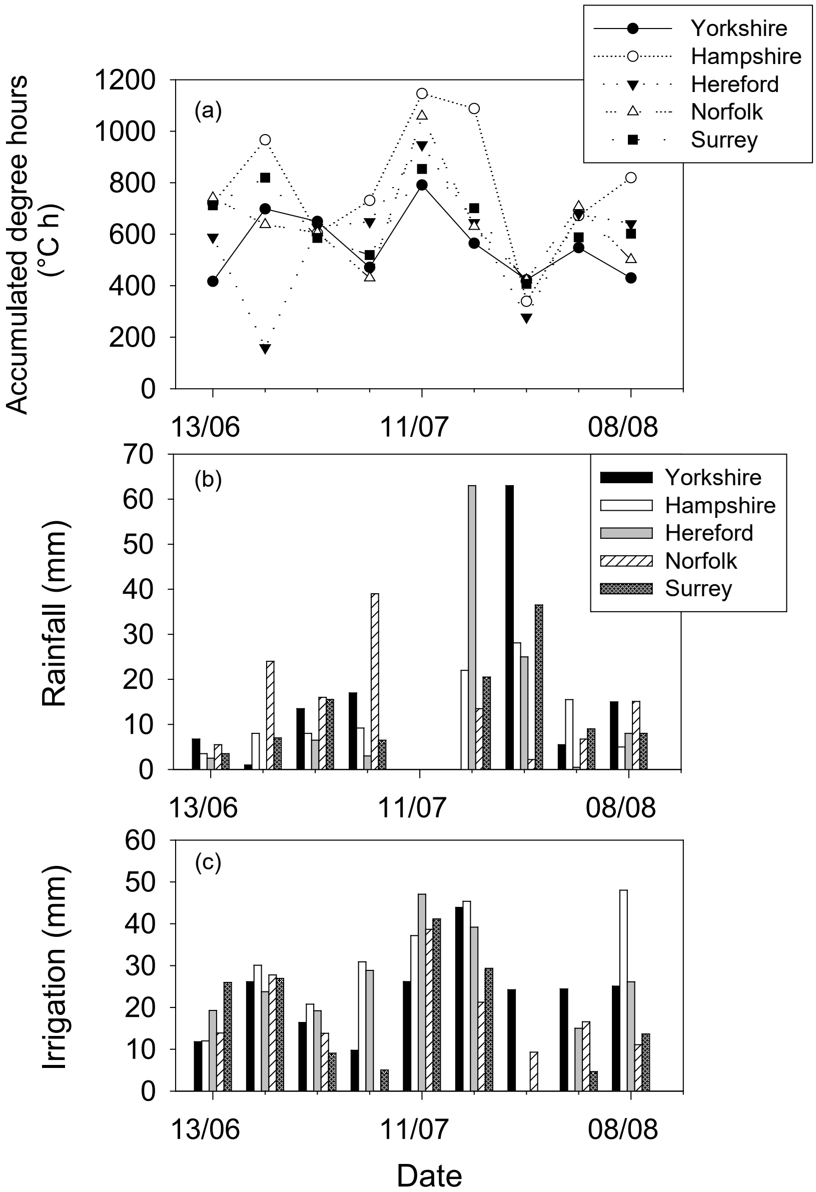

Figure 31. Weekly accumulated degree hours as measured with an Evaposensor (a), total rainfall (b) and irrigation applied (c) for beds on nurseries in different locations in 2005.

In 2006, at the Hampshire nursery water use was much greater on the manually scheduled bed (mean irrigation 8 mm/day) compared to the GP1 scheduled bed (mean 3 mm/day). The GP1 automatic scheduling clearly showed a very significant water saving in this case (Figure 32a). Occasionally, early in the season, a little extra spot hand watering was required on the *Physocarpus* on the GP1 bed to cope with its extra demand compared with the *Spiraea* (Figure 33). Overall, good control was achieved using the GP1. Substrate moisture levels within the controller pot stayed broadly within the 35-45% set point band. Significant deviations outside this were either due to rainfall, additional manual watering, or occasional low points where rapid drying out occurred during very hot days before the evening watering opportunity provided by the master control panel. After 16 July, when the probe was moved to the *Physocarpus*, which has a higher water requirement than the *Spiraea*, the replicate probe indicated that the *Spiraea* pot ran slightly wetter. However, the *Spiraea* generally on this bed were not obviously too wet. Despite large differences in water use between the GP1 and manually controlled beds, there was no obvious evidence of water stress or differences in plant growth between the same species in either location. The GP1 reduced water use by 60% in 2006, a dry year. In 2007, a wet year, differences were not as large but were still substantial: the GP1 on the Hampshire nursery reduced water use by 36% (Figure 32c). On another nursery, in Norfolk, use of the GP1 reduced water use by 43% (Figure 32b). Figure 37 shows how the GP1 on the Norfolk nursery prevented over-irrigation. The irrigation turned off at 35% no matter what the substrate moisture at the start of irrigation. However the irrigation timer was set to turn irrigation on late in the day, so that on some occasions substrate moisture fell quite low before irrigation was applied (to 16% on 5th August in the example in Figure 33).

Influence of rainfall

Despite it being a generally hot and dry summer in 2006, many nurseries experienced some days with very heavy rain. The quantities of both actual rainfall and “useful rainfall” that would contribute to irrigation need, and the useful rain as a percentage of total useful precipitation received by the crop are presented in Table 6. Rainfall thus contributed to between 16% and 38% of the useful precipitation received in 2005, between 9% and 36% of the useful precipitation received in 2006, and between 19% and 47% of the useful precipitation received in 2007.

Table 5. Average daily degree hours, rainfall, and irrigation for a variety of crops on different types of beds, with different sprinkler types and scheduling methods in five locations. Higher degree hours indicate on average hotter or less humid days. “Grower” indicates grower-determined application of irrigation.

Location	Type	Sprinklers	Scheduling	Crop	Degree hours (°C h)	Rainfall (mm)	Irrigation (mm)
2005	= 6 June to 18 September*						
Yorkshire	Mypex	Mamkads	Grower	3 L *Viburnum*	76.2	2	2.96
Hampshire	Mypex	Naan impact	Grower	2 L *Spiraea*	104.6	1	3.53
Hereford	Mypex	Rainbird impact	Grower	3 L *Physocarpus*, 2 L rosemary	85.8	1	3.61
	Mypex	MP Rotators	Grower	3 L *Olearia*			3.08
Norfolk*	Gravel	Widely spaced Naan impact	Grower	3 L *Clematis*	83.3	2	1.79
Surrey	Gravel	Rotoframes	Evaporimeter	9 cm herbaceous	88.3	2	1.93
2006	= 5 June to 17 September						
Yorkshire	Mypex	Mamkads	Grower	3 L lavenders, grasses	81.9	2	6.02
		MP Rotators	Grower	3 L *Viburnum*			2.15
Hampshire	Mypex	Naan impact	Grower	3 L *Spiraea*	119.7	2	8.22
			GP1				3.29
Norfolk	Gravel	Widely spaced Naan impact	Grower	3 L *Sambucus*	75.4	2	5.17
		Narrowly spaced Naan impact	Grower				5.33
Surrey	Gravel	Rotoframes	Evaporimeter	2 L *Penstamon*	103.4	3	2.93
2007	= 4 June to 17 Sept						
Hampshire	Mypex	Naan impact	Grower	3 L *Spiraea*	54.4	3	2.45
			GP1				1.98
Norfolk*	Sand	Naan impact	Grower	3 L *Philadelphus*	69.2	3	5.82
			GP1				2.84
Surrey	Gravel	Rotoframes	Evaporimeter	2 L Heucheras	65.0	3	1.40

* Shorter seasons apply to the Norfolk nursery in 2005 (13 June – 25 Sept) and 2007 (18 June – 17 Sept)

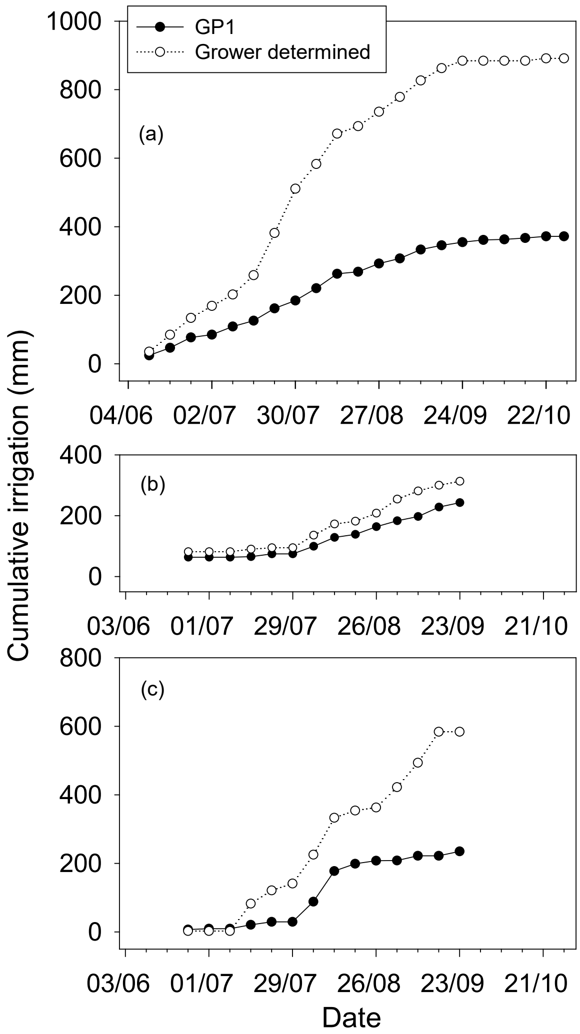

Figure 32. Cumulative weekly irrigation on two beds on a nursery in Hampshire in 2006 (a) and in 2007 (b) and on two beds on a nursery in Norfolk in 2007 (c). On one bed irrigation was scheduled using a GP1 automatic system (closed symbols). On the other irrigation was determined using grower experience (open symbols).

Figure 33. *Physocarpus* growing in drier compost compared to *Spiraea* on GP1-controlled bed 4 July 2006 at the Hampshire nursery.

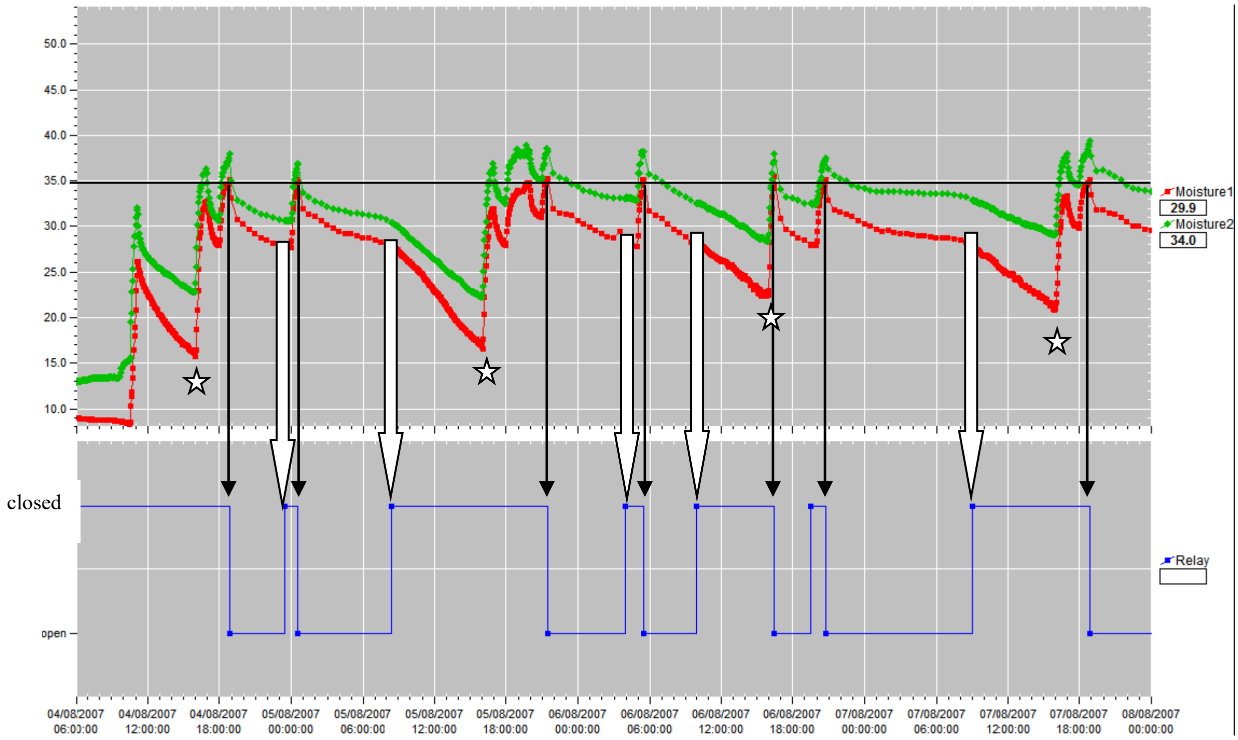

Figure 34. Substrate moisture in the pot used to control the irrigation (Moisture 1) and in another pot on the same bed (Moisture 2) (a) and the status of the relay (b) on the GP1 controlled bed on the Norfolk nursery during the summer of 2007. When Moisture 1 reached 35%, irrigation turned off immediately (thin arrows). When Moisture 1 fell to 28%, the GP1 signals for the irrigation to come on (block arrows), but this may not occur for several hours, depending on the times input into the irrigation timer. The main scheduled irrigation was set at 16 h, causing a rapid increase in substrate moisture (stars). Further application occurred at 18:00 h if the substrate moisture had not yet reached 35%.

Water use indices

Water use indices (WUI) verify that the Surrey nursery's application of water was very efficient three years in a row (Table 6). However, even with this index it is difficult to compare between locations or years. For example, water use efficiency appears, according to the index, to decrease substantially on a grower-scheduled bed in Hampshire between 2005 and 2006, whereas in reality it seems unlikely that grower scheduling would deteriorate. In addition, the index may not work well in a wet year (2007). Perfect scheduling of irrigation to replace water lost by evapotranspiration would lead to a similar water use index on a given HNS bed throughout the season. Figure 35d shows that in fact on different beds WUI varies between weeks. For example, the WUI for a bed on the Yorkshire nursery was higher in the week commencing 3rd July than the following weeks. This is because a relatively large quantity of irrigation was applied that week (Figure 35c) despite relatively low evapotranspiration (indicated by the number of accumulated degree hours, Figure 35a). However, the relatively high WUI value for a bed on the Hampshire nursery week commencing 17th July relates to the rainfall received that week, rather than to particularly high irrigation. Thus the WUI might work better on indoor beds than outdoor beds.

Nonetheless the index can provide some guidance as to where irrigation is being applied perhaps excessively e.g. the high WUI on one of the beds on the Norfolk nursery weeks commencing 3rd July and 10th July probably indicate that the need for irrigation was overestimated in those weeks. The WUI on the Surrey nursery was low throughout the season. That was also the case in 2007 (data not shown).

Using the WUI to compare different scheduling methods, on the Hampshire nursery in 2006, while some variation exists between weeks in the WUI on the GP1-controlled bed, there is far greater variation in the WUI where irrigation was determined by the grower (Figure 36c). On weeks commencing 17th July, 24th July, and 11th September, in particular, the application of irrigation on the "grower determined" bed apparently exceeded the need for irrigation. On the week commencing 11th September in particular, the accumulated degree hours were relatively low (Figure 36a), and rainfall occurred (Figure 36b), limiting the need for irrigation.

Table 6. “Useful” rainfall, useful rainfall plus irrigation, a water use index (WUI), and the percentage of water requirements accounted for by rainfall on different nurseries and for different beds over three years of monitoring.

Location	Type	Sprinklers	Scheduling	“Useful” rainfall	“Useful” rainfall + irrigation (mm)	WUI (mm/100 °C h)	Useful rain as % of useful rain + irrigation
2005	= 6 June to 18 September*						
Yorkshire	Mypex	Mamkads	Grower	1.03	4.00	5.25	26
Hampshire	Mypex	Naan impact	Grower	0.91	4.45	4.25	21
Hereford	Mypex	Rainbird impact	Grower	0.70	4.30	5.02	16
	Mypex	MP Rotators	Grower		3.78	4.40	18
Norfolk*	Gravel	Widely spaced Naan impact	Grower	1.09	2.88	3.46	38
Surrey	Gravel	Rotoframes	Evaporimeter	1.03	2.96	3.35	35
2006	= 5 June to 17 September						
Yorkshire	Mypex	Mamkads	Grower	1.19	7.20	8.80	17
		MP Rotators	Grower		3.33	4.07	36
Hampshire	Mypex	Naan impact	Grower	0.81	9.03	7.54	9
			GP1		4.10	3.43	20
Norfolk	Gravel	Widely spaced Naan impact	Grower	0.92	6.09	8.71	15
		Narrowly spaced Naan impact	Grower		6.25	8.58	15
Surrey	Gravel	Rotoframes	Evaporimeter	0.76	3.70	3.57	21
2007	= 4 June to 17 Sept						
Hampshire	Mypex	Naan impact	Grower	1.55	4.01	7.37	39
			GP1		3.53	6.50	44
Norfolk*	Sand	Naan impact	Grower	1.37	7.18	10.38	19
			GP1		4.20	6.07	32
Surrey	Gravel	Rotoframes	Evaporimeter	1.25	2.66	4.09	47

* Shorter seasons apply to the Norfolk nursery in 2005 (13 June – 25 Sept) and 2007 (18 June – 17 Sept)

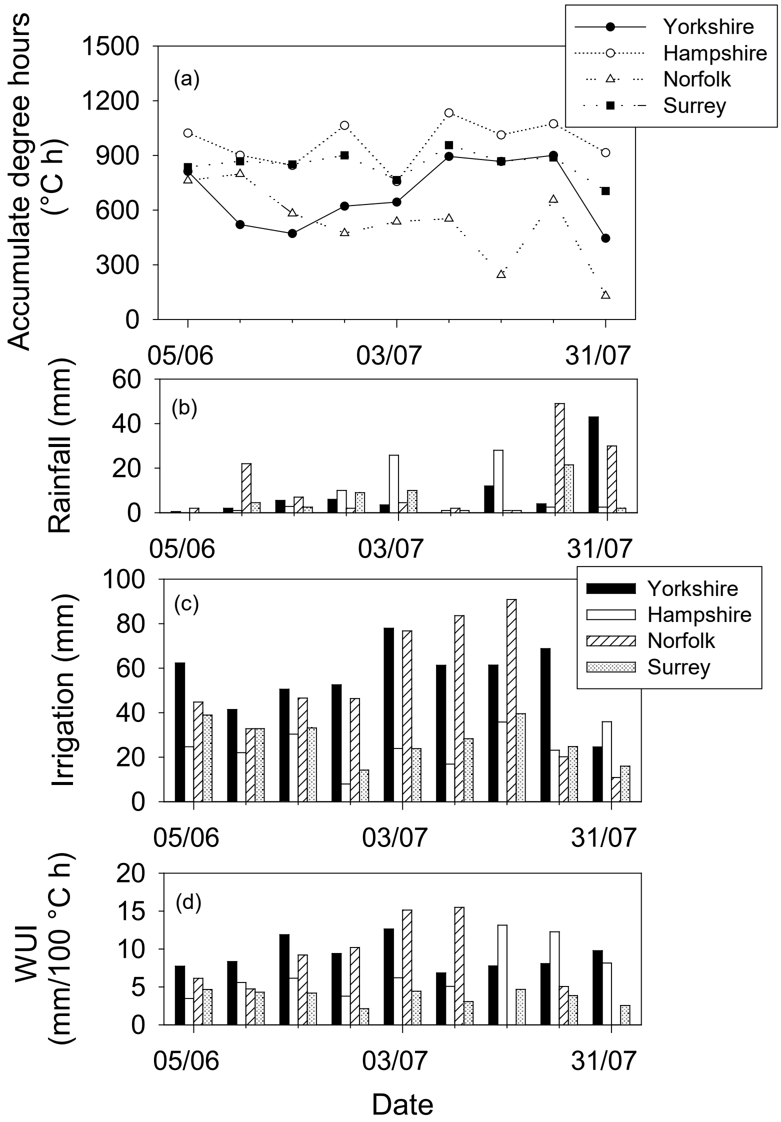

Figure 35. Weekly accumulated degree hours as measured with an Evaposensor (a), total rainfall (b) irrigation applied (c) and a water use index (WUI) of useful precipitation per 100 degree hours for selected beds on nurseries in different locations during part of the monitoring season of 2006 (d). WUI data are missing for weeks commencing 17th and 31st July for the Norfolk nursery.

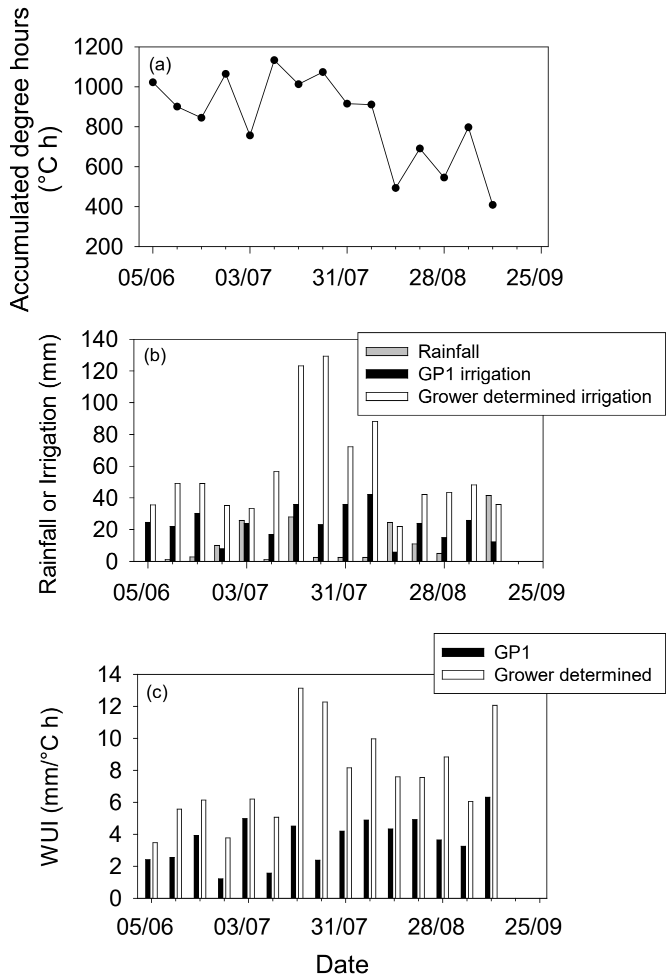

Figure 36. Weekly accumulated degree hours as measured with an Evaposensor (a), total rainfall and irrigation applied (b) and a water use index (WUI) of useful precipitation per 100 degree hours for two beds on a nursery in Hampshire in 2006. On one bed irrigation was scheduled using a GP1 automatic system (closed bars). On the other irrigation was determined using grower experience (open bars).

Discussion

Performance of irrigation systems

On the EMWC uniformity on the MP2000s beds while better than on the rotoframes bed was nonetheless not as good as specified by the distributors. Additionally, the scheduling coefficient was higher than suggested, indicating that more water would have to be used to ensure the plants receiving the least water received enough. However, while MP2000s are advertised as having a Christiansen's Coefficient of Uniformity of 98% and a scheduling coefficient of 1.1, these values are for application to a larger bed with 3 m between nozzles. In the case of our 5 m x 10 m beds it was necessary to have 5 m distance between nozzles across the bed and 2.5 m along the laterals.

It is worth noting that although substantially more water was used on the rotoframe bed than on any other bed in the EMWC, at the Surrey nursery rotoframes were used very effectively. This partly relates to the set-up of the rotoframes (Figure 37), with water from adjacent beds overlapping; as a result a relatively small proportion of plants suffer the “edge effect” that was very noticeable on the EMWC, where some plants receive only half the water received by those between the two sprinklers. The other factor leading to more efficient water use with rotoframes on the Surrey nursery is the use of a scheduling method. It would be of interest to monitor water use on nurseries using rotoframes but no scheduling e.g. small nurseries where timers are set for e.g. half an hour a day. It would also be of interest both to compare the Evaposensor and soil sensor on MP2000s bed with an unscheduled MP2000s bed, and also to compare scheduling of a rotoframes bed to the unscheduled rotoframes bed used on the EMWC.

Comparison of different irrigation sprinklers on different nurseries is to some extent confounded with location, crop, and bed type. Different spacing arrangements of the same sprinklers on the Norfolk nursery had limited effect on the quantity of irrigation applied to the beds. However, different sprinklers and correspondingly different arrangements of sprinklers on the Yorkshire nursery led to strikingly different irrigation water use. The message to growers here is that different arrangements and sprinkler types can lead to drastic reductions in water use, and therefore it is worth trying different arrangements, but before investing in large quantities of new sprinklers or pipework, it is important to test the uniformity and application rate. This can be done as described in Factsheet 16/05 and demonstrated in Figure 37 where saucers have been arranged at intervals in a section of the bed, under the sprinklers. The data are then input into the HDC Irrigation Calculator to produce graphs and figures of the type included in the Results Section. In this way different arrangement of sprinklers can be quite rapidly compared.

It is clear that uniformity of overhead irrigation is greatly affected by wind, so this needs to be taken into account when deciding on a suitable arrangement. On the EMWC output from the gantry was little affected by wind. Uniformity under the gantry was very high, and the scheduling coefficient very close to 1, indicating that all plants receive the same amount of water. Water use on this bed was lower than on a comparable bed with conventional overhead irrigation. The difference, 8 m^3 (or 169 mm), is not very large, but if a gantry could be used over large areas of a nursery the water savings could be substantial. A gantry is clearly may not be suited to every nursery, and the capital cost (approx. £3,000) is inhibitive for smaller nurseries; additionally leveling of beds is required. For larger nurseries, the cost may be justified if the advantages are sufficient. Increased uniformity of plants or increased quality would be such an advantage, but our study did not indicate that quality was notably greater on the gantry bed. Water use under the gantry with scheduling using an

Evaposensor was comparable to that under MP2000s with scheduling using soil moisture sensor. It would therefore be of much interest to investigate the advantages in water savings of scheduling a gantry with a soil moisture sensor.

Although Mypex has the advantage over gravel of allowing plants to take up water from the bed surface, and hence reducing wastage of irrigation, maintenance of surface water over winter on the Mypex bed on the EMWC apparently had a deleterious effect on root quality. If water is recycled, then although more water needs to be used on gravel than Mypex, some of the extra water used on the gravel can be collected and re-used. Less water was used on the Efford sand bed than on any other system on the EMWC, two years in a row. There are other advantages of using the Efford sand bed, such as keeping leaves dry and therefore less prone to disease, and reducing the incidence of mosses and liverworts. Substrate moisture on this bed was generally more uniform than on other beds, which may partly explain the high quality of plants on this bed (particularly noticeable after the dry summer of 2006). Additionally, the Efford bed can be drained over winter. However, an Efford sand bed needs to be perfectly level and perfectly sealed and thus installation is more time-consuming than for other systems. Some subjectivity is involved in choosing the level of water in the sand. This is also a difficult bed to maintain, since weeds and algae accumulate on the sand. On the other hand, in terms of irrigation management, once the plants are established very little further management is required. In this, the soil sensor compares favourably with the Evaposensor or evaporimeter, both of which require daily readings.

No matter what irrigation system is used, it is important to attempt to group crops on beds according to their irrigation demand, in order to avoid having to hand-water those crops with greater demand for water. A potentially significant advantage of gantry irrigation would be to use sprinklers with different outputs on different sections of the boom, and group plants with different water requirements accordingly.

Figure 37. Rotoframe set-up on the Surrey nursery.

Scheduling

It is clear from Figures 18, 19, 31, and 32 that environmental conditions fluctuate from day to day and week to week, and that therefore a crop's requirement for water also fluctuates. For this reason it is not surprising that both on the EMWC and on commercial nurseries, use of scheduling methods reduced irrigation water use. The growers in this study were already using a form of scheduling, in that they use their experience of crop water requirements, knowledge of the weather, weather forecasts, pot weights etc. to determine whether or not to irrigate, and for how long to irrigate. For this reason, grower-determined irrigation often parallels scheduling using sensors. Such grower-determined irrigation is far superior to the timer-controlled irrigation on one of the beds on the EMWC, where no attempt was made to alter the length of irrigation runs in accordance with daily weather or any other measure of plant water requirements. Similar timer-controlled irrigation is common on smaller nurseries. Although daily decisions by an irrigation manager can be very effective in improving the efficiency of irrigation use, it is apparent from results on different nurseries that efficiency can be further improved by use of sensors for scheduling.

The bucket evaporimeter used on the Surrey nursery is a cheap system and straightforward to use. On the Surrey nursery, irrigation is turned on for a sufficient length of time to replace the number of mm water lost from the bucket. However, since different crops require different quantities of water, fudge factors have to be introduced to successfully replace water from all the crops. Calibration by weighing pots could remove the guess-work from this system. The bucket evaporimeter has the advantage of automatically taking rainfall into account, since rainfall accumulates in the bucket. It would be of interest to monitor water use on any other nurseries with scheduling using the bucket evaporimeter, perhaps with different irrigation set-ups or different crops.

The Evaposensor, like the bucket evaporimeter, has the advantage that one sensor can be used to schedule several beds. On the EMWC, the same Evaposensor was used to schedule three beds, each with separate calibration factors. A disadvantage is that the Evaposensor system is not currently automated, so it needs to be read frequently and the irrigation set accordingly. In addition, it does not take into account rainfall. However, we found that reading the Evaposensor and a small rain gauge and using simple calculations to convert to the required length of an irrigation run worked well. The main disadvantage, therefore, is possibly not the need to read the Evaposensor frequently but the need to calibrate it against plant water use. This calibration needs to be repeated as the plants grow. It should be noted that if plants are not well-watered when this calibration is undertaken, their stomata will not be fully open and so water use would not reflect the real water use of these plants when well-watered. Using a calibration undertaken in these circumstances would lead to plants receiving too little water. The need to undertake calibrations, however, is likely to become less frequent for a grower who uses the Evaposensor and similar crops in consecutive years, since calibration factors for plants at a similar stage in previous years can probably be applied.

The soil sensor system has the advantage of being automated. However, a disadvantage is that it relies on a measurement in only one pot. Where different species have different water use on the same bed, the choice of species to act as the control is therefore critical. In addition, since we have seen above that irrigation is not uniform on overhead irrigated beds, the location on the bed where the sensor is installed will greatly influence the irrigation. On the EMWC, water use was less where the soil sensor was used to schedule irrigation than where the Evaposensor was used. The difference (8 m^3, or 169 mm) may not be sufficient in all cases to justify the extra cost involved if a GP1 needs to be installed on each of several different beds on a nursery, as opposed to one Evaposensor and Evapometer for several beds. On the other hand, since the GP1 is an automatic system, the need to spend time on irrigation management with this system is less than in the case of the Evaposensor. In some cases the savings on labour costs may outweigh the capital expenditure. On this note, the need for daily adjustments to irrigation is completely removed with the Efford sand bed. The best scheduling option to choose will depend on the specific layout, beds, crops etc. on a given nursery. Figure 34 highlights the potential dangers associated the use of irrigation timers: substrate moisture can become quite low on hot, sunny days if irrigation is not set to turn on until quite late in the day. This problem is not unique to the use of a GP1 – it could equally occur with any other scheduling system if irrigation is not applied until the evening. On the EMWC, application of irrigation four times a day prevented this occurrence, and also prevented excessive run-through; however application of water during the day can lead to greater losses of water due to evaporation.

<u>Bench-marking of nursery irrigation</u>

It is tempting to use the results of WUMS to indicate bench-marking data for assessment of good irrigation management. However, it should be appreciated that all nurseries that participated in this project are already aware of the value of good irrigation management. Some were already involved in HNS 97. None of the nurseries, for example, simply set a timer to turn on every day and then ignore it. The reality is that many nurseries will have far higher water consumption than those in this study. Therefore it is more useful to consider the values provided here as targets that other nurseries can aim for. Differences between different systems can be taken on board by growers when deciding what system to use. It is also worth noting that some of the growers involved in this study tend to “run the crop dry”. They are effectively using deficit irrigation. Whether this is suitable for all crops and all circumstances is as yet unclear. Finally, hand-watering, although limited on these nursery beds, was not included in the total water use values. It would not be useful for other nurseries to achieve the values described here with their irrigation systems, but then to add a substantial quantity of water by hand-watering. Indeed, removing the need to hand-water is an important aspect of irrigation management. The idea of the water use index used here, which potentially allows comparison between different locations with different meso- or micro-climates, needs to be tested and developed further before application in bench-marking.

The overall average water use per day, taking the three years of monitoring and all the different beds into account, was 3.6 mm/day. This compares with on average 1.5 mm/day for protected ornamentals and 3.1 mm/day for crops such as tomato, cucumber or pepper – however in the latter case peaks of up to 12 mm/day occur in summer. Values obtained on the EMWC are high, when converted to mm, are high in comparison to nursery values: even the Efford sand bed, on which the least water was used, averaged more than 4 mm/day in 2007, and almost 7 mm/day in the drier summer of 2006. On the beds on which irrigation was scheduled, between 4 and 7 mm/day was used in 2007 and between 7 and 10 mm/day was used in 2006. The main reasons for higher values on the EMWC than on several of the nursery beds are (a) no hand-watering was applied on the EMWC so sufficient irrigation had to be applied to ensure that all plants received enough irrigation, all of the time, and (b) on the nurseries involved in this project, plants tend to be run dry, whereas on the EMWC it was not considered desirable to impose any deficit irrigation, as that is the subject of another project (HNS 141).

<u>Uniformity</u>

It might be expected that a less uniform irrigation system would lead to less uniform plants, in terms of plant size and plant quality. However, overall research on the EMWC gave no consistent indication of increased uniformity on more irrigation-efficient systems. This is surprising given the greater variation across beds in substrate moisture apparent with certain systems. On the other hand the result is consistent with patterns emerging in HNS 141 (4th Interim Report April 2007) in which overhead irrigation, though less uniform than drip irrigation in its water distribution, did not lead to decreased uniformity in pot weights, substrate moisture, or plant size as compared to drip. Nonetheless, in the HNS 141 study the overhead irrigation used was as uniform as possible (CU of > 90%) and was used in a protected environment – far greater differences in uniformity of irrigation occurred on the EMWC between beds than between drip and overhead irrigation in the HNS 141 study, which would have been expected to lead to greater differences in uniformity of plants.

The potential advantage of improving plant uniformity by improved irrigation management is therefore not evident in this study. However, uniformity was not decreased in the more irrigation-efficient systems, so better irrigation management can maintain plant uniformity while using less water. For many growers, the advantages of reducing the labour costs associated with hand-watering and daily decisions regarding irrigation would, in any case, outweigh the potential advantages of increased uniformity.

Decision support

The possibility of creating a “decision support tool” for growers, as a future project, was discussed by the steering committee of this project. It was agreed that such a tool should focus on the decisions that need to be made by growers who wish to improve their existing system, rather than by those who are setting up new nurseries or expanding. It is not possible to deal with all aspects of such decisions using the work undertaken in this project alone, since in this project it was only possible to study a subsample of the many combinations of sprinklers, HNS beds, scheduling techniques etc. available. Such a tool could, however, be created combining results from HNS 122, HNS 38, HNS 38a, HNS 97, HNS 107a, HNS 141, and research undertaken in other countries.

Conclusions

On the EMWC, substantial water savings were achieved through the combination of an “improved” overhead irrigation system and scheduling in response to plant demand for water, as compared to a less optimal overhead irrigation system and not scheduling irrigation. Even with “improved” overhead irrigation there is considerable non-uniformity of water distribution over a bed, particularly on windy days, and the effects of this were seen in very non-uniform substrate moisture across some of the beds. Plant growth varied between beds, but the trends in plant growth were not consistent across different subjects.

The results from the WUMS over three years have indicated that there can be very large differences (up to 6-fold) in water consumption between nurseries or beds growing broadly similar crop subjects. Water was used much more efficiently and economically where some methodical scheduling method was practiced.

- Scheduling irrigation according to plant demand for water, in combination with “improved” overhead irrigation, resulted in substantial water savings compared to a “typical” industry standard system.
- Plant quality was as good or better under those systems which used the least water as under the system which used more water.
- On nurseries, the use of sensors for scheduling irrigation reduced water use.
- Certain arrangements and types of sprinklers increased nursery water use efficiency.

Technology transfer

Grower visits

HDC HNS Panel visit 13th September 2005

EMR Open Trade Day 22nd September 2005

HDC HNS Panel visit 7th June 2006

West Sussex Fruit Growers visit 18th July 2006

Kent Ambassadors visit 20th July 2006

Fruit Focus 26th July 2006

East Malling Water Centre Open Day September 2006 (cancelled by HDC)

HDC HNS Panel visit 6th December 2006

Nuffield Scholar visit 12th July 2007

British Ornamental Plant Association 17th July 2007

SEEDA visit 26th July 2007

Kent Horticultural Discussion Group, 31st July 2007

HDC Irrigation Open Day 11th September 2007 – included presentations on results from the EMWC and from WUMS, and a tour and discussion of the EMWC

Presentations

A summary of the treatments and some results was prepared for HDC for inclusion in Four Oaks 5th September 2006

Poster presented at DEFRA Water Day at HRI Warwick, 20th July 2006

EMRA Water Day 30th November 2006

Articles

Indexing your way to water saving. HDC News April 2006, issue 122, p. 19-22.

Irrigation management in nursery stock. HDC News September 2006, issue 126, p. 8.

Benchmarking nursery water use HDC News April 2007, issue 132, p. 24-25.

Water know-how. HDC News June 2007, issue 134, p. 12-13.

Costa JM, Grant OM, Ortuña MF (2007). Strategies to save water in intensive horticulture. Fruit and Veg Tech, issue 7.3, 12-14.

Factsheet

Factsheet 16/05 Measuring and improving performance of overhead irrigation for container-grown crops

Pamphlet

The East Malling Water Centre – a facility for container plant research – produced September 2007

Glossary

Evaporative demand – the power of an environment to evaporate water. It differs from humidity in that it takes into account other factors that influence evaporation e.g. radiation.

Evaposensor – an instrument invented at HRI East Malling and now available from Skye Instruments that provides an electrical signal approximately proportional to potential transpiration from a model leaf. It integrates the effects of humidity, radiation, temperature, and wind.

ET_p – potential evapotranspiration – the rate at which a crop would lose water under prevailing environmental conditions if water supply was non-limiting. It includes evaporation from the plants i.e. transpiration and from the soil – or in the case of this work from the substrate in the container.

Scheduling coefficient – a measure of the effect of non-uniformity of irrigation on the degree of over-irrigation required if the driest areas are to receive the intended (i.e. mean) volume of irrigation. It is defined as the mean catch rate divided by the minimum catch rate.

Volumetric substrate moisture content – water content of the substrate expressed as a fraction or percentage of the total volume occupied by water. Its maximum value, when the substrate is saturated, depends on the percentage of pore space in the substrate, which in peat based substrate is generally about 90%.

References

ADAS Independent Water Audit for Container Grown Nursery Stock Producers – Summer 2000.

HDC HNS 38 Water use under different hardy nursery stock container systems. Final Report 1995.

HDC HNS 38a Estimating irrigation needs for HNS in containers. Final Report 1994.

HDC HNS 97/Horticulture LINK project 201 Improving the control and efficiency of water use in container-grown hardy ornamental nursery stock. Final Report 2003.

HDC HNS 107a Container HNS: Improving water management within growing media. Final Report 2003.

HDC HNS 141 Enhancing the quality of hardy nursery stock and sustainability of the industry through novel water-saving techniques. 4th Interim Report April 2007.

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