Project title:	Developing optimum irrigation guidelines for reduced peat, peat-free and industry standard substrates
Project number:	HNS 182
Project leader:	Dr Mark A. Else, East Malling Research
Report:	Final Report, June 2013
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Date project commenced:	1 April 2010
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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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CONTENTS

GROWER SUMMARY

Headlines

- Plant quality in each of the three substrates was similar when substrate moisture contents were optimised
- The automated irrigation scheduling tool prevented over-irrigation following the frequent and heavy rain showers during the summer of 2012
- Irrigation scheduling regimes that reduced or eliminated run-through were developed for drip, overhead and sub-surface irrigation to industry standard, reduced peat and peat-free substrates

Background and expected deliverables

Following a consultation period (ending 11th March 2011), Defra outlined plans to reduce the horticultural use of peat in England in the Natural Environment White Paper published in June 2011. The White Paper included an ambition to reduce horticultural peat use to zero in England by 2030, setting the following milestones: a progressive 2015 target for new contracts in the public sector, a 2020 voluntary target for amateur gardeners and a 2030 voluntary target for commercial growers. The Sustainable Growing Media Task Force was established in June 2011 and has since adjusted its remit to that of putting the horticultural sector on a long-term sustainable footing by ensuring that all choices of growing media (or substrate) used for amateur gardening and horticulture are sustainable. The HNS industry's views on peat replacement and peat alternatives are set out in the HDC News Growing Media Review.

Most growers acknowledge that irrigation and nutrient regimes will need to be modified when using reduced peat and peat-free substrates. The relatively poor water-holding capacity of most peat-free alternatives will necessitate more frequent irrigation events but over-watering must be avoided to minimise run-through of water and dissolved fertilisers and limit environmental pollution. Growers will face increasing pressure to use water more efficiently, due to restrictions on future water use and drip/trickle irrigation is to be brought under legislation in April 2014. Improved irrigation scheduling guidelines for HNS media will help growers to comply with legislation, optimise plant quality, reduce costs and gain confidence in growing HNS in peat alternatives.

Summary of the project and main conclusions

Substrates

The following substrates were selected after consultation with members of the Project Steering Group; the substrates are considered to be good quality brands that are (or are becoming) widely used by UK growers:

- **Industry standard**: substrate: 25% bark, 75% peat (William Sinclair Horticulture Ltd)
- **Reduced peat**: substrate: 25% wood fibre, 25% bark, 50% peat (Bulrush Ltd)
- **Peat-free**: peat-free materials (composted green waste and bark) (Vital Earth Ltd)

Plant species

The following widely-produced crops were chosen for experiments after consultation with members of the Project Steering Group; these species were considered moderately resilient to substrate drying and therefore a good choice of 'indicator' species:

- *Ribes sanguineum* 'Koja'
- *Escallonia rubra* 'Red Dream'
- *Sidalcea* 'Party Girl'

Experimental site

All experiments were conducted on the East Malling Water Centre (EMWC) (Figure GS1). Plants were placed either on 10 m x 5 m gravel beds with overhead irrigation or on 1 m^2 square plots of mypex overlaying outdoor capillary matting and polythene, on a sand bed measuring 10 m x 5 m on the EMWC.

Figure GS1. Experimental plots of *Sidalcea*, *Ribes*, and *Escallonia* plants potted in industry standard, reduced peat or peat-free substrates. Sub-surface irrigation bed, EMWC, July 2012.

Irrigation delivery

Overhead irrigation was applied by six MP rotator 2000 overhead sprinklers spaced 2.5 m apart along the west and east edges of each bed. Sub-surface irrigation was applied using T-tape irrigation tubing supplied via a 3/4" low flow pressure regulator. Each plot was irrigated by two lines of T-tape tubing spaced 60 cm apart, each with six emitters at 15 cm spacing. Water was sourced from the mains and the timing and duration of irrigation events was controlled using Galcon DC-4S controllers.

Irrigation scheduling

Irrigation was scheduled automatically using Delta-T SM200 moisture probes connected to Delta-T GP1 data loggers. The moisture probes were inserted through holes drilled through the side of the plastic pot 6 cm below the substrate surface and were located in a representative experimental pot for each substrate. To maintain volumetric substrate moisture content (VSMC) and plant-and-pot weights within the optimal range identified in Year 1 for each crop and substrate, irrigation set points were adjusted when necessary. Irrigation was scheduled according to the requirements of the crop with the highest transpiration rate; in each substrate this was *Escallonia*. Plant-and-pot weights were measured before and after irrigation during the growing season and the duration of irrigation events were then adjusted to minimise run-through and wastage of water.

Plant growth and physiology

Routine measurements of plant-and-pot weights for plants given overhead irrigation, and plant physiological responses under both irrigation treatments were made weekly during the growing season to determine whether the irrigation regimes imposed to maintain the 'optimal' moisture contents for each substrate promoted strong, healthy plant growth, or resulted in plant stress during periods of high evaporative demand.

Plant quality

Plant quality in each of the three HNS species in each substrate was assessed by members of the Project Steering Group in May 2013. A score of 5 represented excellent quality, 3 was deemed to be marketable and a score of 1 indicated very poor quality.

Results

Substrate volumetric moisture contents

For most substrate / species combinations receiving overhead irrigation or sub-surface irrigation, average plant-and-pot weights or VSMCs were maintained within the optimal ranges identified earlier in the project. The exception was *Escallonia* plants in reduced peat substrate where the average plant-and-pot weight fell below the lower irrigation set point at the end of August and the beginning of September 2012. Further investigation revealed that the pot in which the SM200 probe was located was no longer representative of the *Escallonia* crop and so the probe was re-located to another experimental pot within the same plot. A similar issue resulted in the VSMC being temporarily below the lower set point for *Escallonia* in peat-free substrate in mid-September.

Irrigation scheduling during periods of heavy rainfall

Scheduling irrigation to uncovered crops following rainfall events can be difficult for HNS growers due to the uncertainty over how much of the rain fell onto the substrate surface, or how much was intercepted by the canopy and channelled into the pot. In the HNS industry, 5 mm of rainfall or more is generally considered to be 'effective rainfall' i.e. sufficient to raise VSMCs. However, it is difficult for growers to decide when to resume irrigation following 'effective rainfall', especially if the weather continues to be changeable. The automated irrigation system used in conjunction with the lower irrigation set points developed in this project effectively removes the uncertainty following rainfall events; this system prevented over-irrigation of the HNS crops during the very wet summer of 2012 (Figure GS 2).

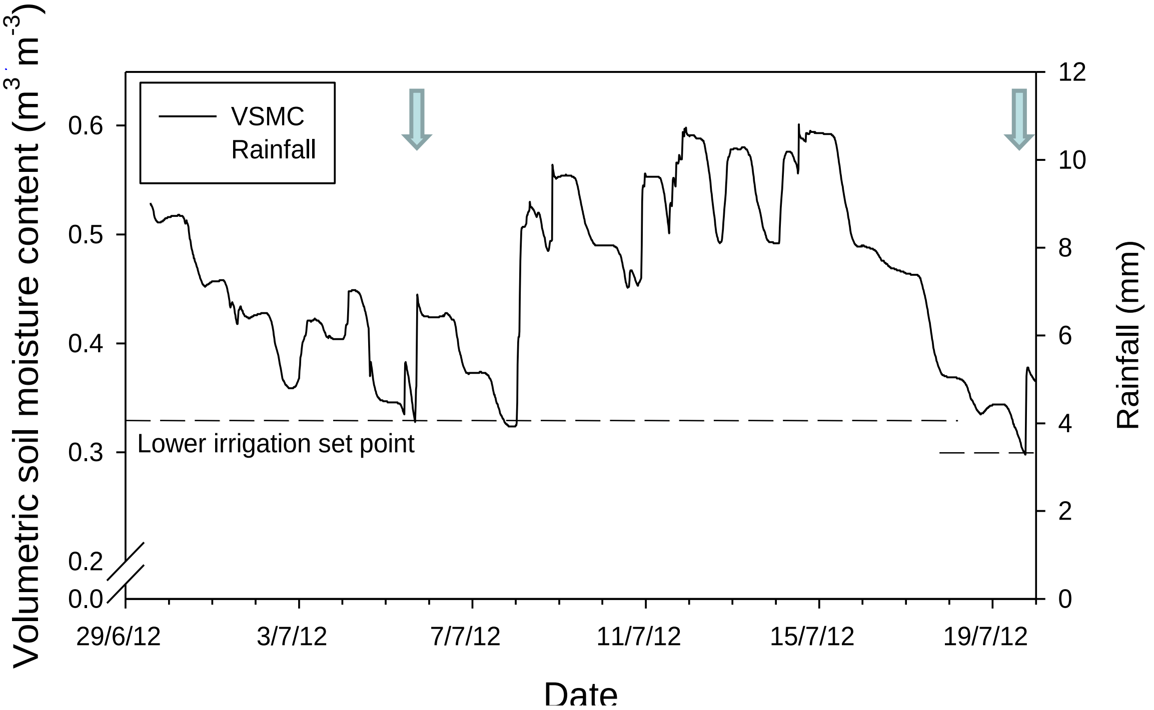

Figure GS2. Automated irrigation scheduling prevented over-irrigation of *Escallonia* plants during the wet summer of 2012. Irrigation was triggered automatically on two occasions between 29 June and 19 July 2013 (indicated by the arrows), otherwise, VSMC was maintained above the lower irrigation set points (dashed lines) by frequent and heavy rainfall (blue bars).

Plant growth and physiology

Measurements of whole-plant transpiration were made at intervals throughout the season to establish whether the ‘optimum’ substrate moisture contents allowed plants to transpire freely and avoided stress associated with limited substrate water availability under conditions of high evaporative demand. For plants given overhead irrigation, transpiration was measured throughout the experiment; *Escallonia* and *Ribes* had higher rates of transpiration than *Sidalcea* and these differences were significant on some dates.

For plants receiving sub-surface irrigation, transpiration was measured during July and early August 2012. Significant differences were seen on some dates between substrates when transpiration rates of *Escallonia* and *Ribes* were significantly higher than those of *Sidalcea*. These measurements confirmed that plants were transpiring freely and that substrate water availability was not limiting under the irrigation regimes imposed.

Plant quality

At the end of June 2012, following a cold and wet period, plants in the peat-free substrate were exhibiting signs of chlorosis. Analysis of the substrate indicated that insufficient nitrogen mineralisation had taken place, probably due to the weather conditions. Therefore, plants in peat-free substrate were each given 100 mg nitrogen (applied as 100 mL 6.45 g L^{-1} $CaNO_3$ solution to each pot) on 25 June 2012.

Estimates of overall plant quality made by members of the Project Steering Group in May 2013 indicated that there were no significant effects of the three substrates on plant quality in the overhead irrigation treatment. However, when sub-surface irrigation was applied (*via* capillary matting), plant quality of *Escallonia* grown in the reduced peat substrate was reduced compared to plants in the industry standard and peat-free substrates, although this effect was just outside statistical significance. The quality of *Sidalcea* and *Ribes* was similar in each of the three substrates.

In plants receiving overhead irrigation, moss coverage was significantly higher in pots of *Sidalcea* and on the surface of the peat-free substrate. Moss coverage was, unsurprisingly, lower in pots receiving sub-surface irrigation than those receiving irrigation overhead. Levels of liverwort were significantly higher in pots of *Sidalcea* receiving overhead irrigation but there were no significant differences in the levels of liverworts on each of the three substrates. Under the sub-surface irrigation regime, the incidence of liverworts was very low and there were no significant differences between species or substrates.

Main Conclusions

- VSMC values at which plant physiological responses are triggered were identified for *Sidalcea*, *Ribes* and *Escallonia* grown in industry standard, reduced peat and peat-free substrates.
- The 'optimum' range of VSMC and plant-and-pot weights in each substrate were determined for *Sidalcea, Ribes and Escallonia* and maintained throughout two growing seasons using drip irrigation, overhead irrigation and sub-surface irrigation.
- Water holding capacity of substrates was 30-50% less in peat-free substrate than industry standard substrate and the water holding capacity in peat-reduced and peat-free substrates varied with crop.
- Irrigation frequency was higher for crops growing in peat-free substrate compared to plants growing in industry standard and reduced peat substrates.
- Plant growth and quality in peat-free and reduced peat substrates were similar to those in industry standard substrate, when irrigation scheduling was optimised.
- The occurrence of mosses and liverworts on the surface of the substrate was greatest for *Sidalcea* receiving overhead irrigation.
- Moss coverage was greatest on the surface of the peat-free substrate under overhead irrigation.
- An automated irrigation scheduling tool that has previously been tested on commercial nurseries in HortLINK 97b experiments was used to maintain 'optimum' VSMCs under drip, overhead and sub-surface irrigation.
- The automated irrigation scheduling tool prevented over-irrigation of plants during the heavy and frequent rainfall in 2012.
- The approaches developed in this project could be used to identify the optimum range of substrate moisture contents in a range of sustainable growing media.

Financial Benefits

A preliminary cost benefit analysis was included in the First Annual Report for HNS 182. Figures provided by Will George (ADAS consultant), from the Horticultural Trade Association's Nursery Business Improvement Scheme (NBIS) suggest that the average value of plant waste from five nurseries during the period 2002 – 2004 was between £21,000 - £27,000 per annum or between 7 and 10% of turnover. Poor watering of peat-based growing media accounted for 3.2% of the waste, which equates to a loss of approximately £1,000 for each nursery per year. This project aims to minimise losses through poor watering during the transition to reduced-peat and peat-free substrates which could be much more substantial than those reported for peat-based media.

Action points for growers

- Consider scheduling irrigation to all substrates using measurements of plant-and-pot weights using an electronic balance, VSMC using a soil moisture probe or estimates of evapotranspiration in combination with crop coefficients using an evapometer.
- Measure volumes of water delivered over a set time by different nozzles used on the nursery (see Factsheet 16/05).
- Install water meters so that the volumes of water applied over the season to different crops can be measured.
- Identify the upper and lower target plant-and-pot weights for each substrate.
- Measure the duration of irrigation needed to achieve less than 5% run-through at the lower irrigation set point for each substrate.
- Irrigation duration for peat-free substrates should be reduced by approximately 30-50% compared to industry-standard substrates to prevent over-watering.
- Irrigation duration for reduced peat substrates can be similar to industry-standard peat-based substrates but may need to be reduced with some crops in order to minimise run-through.

SCIENCE SECTION

Introduction

The HNS sector is the largest user of peat in the UK horticultural industry[1]. Around 450,000 m^3 of growing medium, of which about 80% is peat, is used annually for hardy nursery stock production in the UK[2]. The UK horticultural industry, and the HNS sector in particular, is over-reliant on peat and the second consecutive poor peat harvest across Europe is predicted to lead to shortages of growing media and increased prices, with peat being imported into the UK from Canada and further afield. The extreme climatic events that result in poor harvest are projected to become more frequent in the future due to the predicted effects of climate change on UK weather patterns. The transition to sustainable growing media and away from an over-reliance on a finite and controversial material, peat, will help to improve the long term sustainability of the sector.

Following a consultation period (ending 11th March 2011), Defra outlined plans to reduce the horticultural use of peat in England in the Natural Environment White Paper published in June 2011[3]. The White Paper included an ambition to reduce horticultural peat use to zero in England by 2030, setting the following milestones: a progressive 2015 target for new contracts in the public sector, a 2020 voluntary target for amateur gardeners and a 2030 voluntary target for commercial growers. It also included a commitment to establishing a Task Force to advise on how best to overcome the barriers to reducing peat use. The proposed withdrawal of peat from the UK horticulture industry was of great concern to many HNS growers and there was strong industry support for this programme of applied research.

The Sustainable Growing Media Task Force was established in June 2011 and has since adjusted its remit to that of putting the horticultural sector on a long-term sustainable footing by ensuring that all choices of growing media (or substrate) used for amateur gardening and horticulture are sustainable. This does not mean that the use of peat is no longer an issue. Instead peat is now to be considered alongside the replacement materials and all materials will be assessed against the same set of criteria.

Recent research[4] has shown that growing HNS in 100% alternatives to peat, such as coconut fibres or pine bark, can be as successful in terms of resulting in the same plant growth and quality as produced in peat. There are potential advantages from using reduced-peat growing media which are not currently being exploited due to concerns about how best to manage irrigation and fertigation regimes. For example, rooting is often improved in better draining media and the drier surface reduces moss and liverwort growth, which could help to reduce labour costs associated with the preparation of plants for dispatch. The impact of over-watering on crop losses and plant quality is likely to be lower when using reduced-peat media, as are losses due to root death caused by over-wet substrates during winter.

A major reason for the limited uptake of non-peat substrates by HNS growers is a lack of confidence in how to manage peat alternatives. This includes uncertainty with respect to irrigation and nutrition[4]. The relatively poor water-holding capacity of most peat-free alternatives will necessitate more frequent irrigation events but over-watering must be avoided to minimise run-through of water and dissolved fertilisers and limit environmental pollution. The need to irrigate commercial crops is often judged by visual assessment. The colour of peat changes from dark to light brown when dry, but with reduced peat or peat-free substrates, the top layer tends to dry out very quickly (increasingly so, the higher the percentage replacement). As a result, reduced peat or peat-free substrates are often over-watered, as they appear to be drying out when in fact lower layers are still wet.

Over-watering can also lead to nutrient leaching, particularly nitrates and phosphates, which is both wasteful and environmentally undesirable. Peat alternatives do not necessarily have the same capacity to retain nutrients as peat, and the most commonly used system of nutrition in HNS production, Controlled Release Fertilisers (CRFs), was developed for peat. The ratios of N:P:K available have also been designed for use in peat substrates. This, coupled with over-watering, can lead to poor plant nutrition. It is likely that specific fertiliser regimes will need to be developed for reduced peat and peat-free substrates. This work will be important to optimise crop quality but is beyond the scope of this project.

Most growers acknowledge that irrigation and nutrient regimes will need to be modified when using reduced peat and peat-free substrates. The relatively poor water-holding capacity of most peat-free alternatives will necessitate more frequent irrigation events but over-watering must be avoided to minimise run-through of water and dissolved fertilisers and limit environmental pollution. Growers will face increasing pressure to use water more efficiently, due to restrictions on future water use and legislation arising from the EU Water Framework Directive (which is aimed at restricting diffuse pollution from fertilisers). To help facilitate the development of ‘best’ or ‘better’ grower practice during the transition to peat-free production, new scientifically-derived irrigation guidelines are needed that maintain an optimum substrate moisture content for reduced peat and peat-free media likely to be used by HNS growers in the future.

In this project, the ‘optimum’ substrate moisture content is defined as one that supports good, healthy plant growth while avoiding over-wet conditions, so that leaching of irrigation water and fertilisers is minimised or eliminated. Irrigation set points have been identified for each substrate, which could be used to develop new water-saving irrigation guidelines for growers wishing to trial reduced peat and peat-free alternatives. Improved irrigation scheduling guidelines for reduced peat, peat-free and industry standard media will help growers to comply with legislation, optimise plant quality, reduce costs and gain confidence in growing HNS in peat alternatives.

Materials and Methods

Industry standard, reduced peat and peat-free substrates

The following substrates were chosen after consultation with the Project Steering Group; the reason for choice of brand was that these substrates are (or are becoming) widely used by UK growers:

- **Industry standard**: substrate: 25% bark, 75% peat (William Sinclair Horticulture Ltd)
- **Reduced peat**: substrate: 25% wood fibre, 25% bark, 50% peat (Bulrush Ltd)
- **Peat-free**: peat-free materials (composted green waste and bark) (Vital Earth Ltd)

Plant material and growth conditions

Experimental plant species were selected after consultation with the Project Steering Group. The following widely-produced crops were chosen as they were considered moderately resilient to substrate drying and therefore a good choice of ‘indicator’ species:

- *Ribes sanguineum* ‘Koja’
- *Escallonia rubra* ‘Red Dream’
- *Sidalcea* ‘Party Girl’

In year 3, to assess the wider relevance of the research, the HNS crops *Verbascum*, *Choisya ternata* and *Philadelphus* were used as guard rows on beds with overhead irrigation. These crops were chosen by the Project Steering Group as their irrigation requirements are similar to those of *Sidalcea*, *Ribes* and *Escallonia*, respectively. These plants were not assessed but general observations of plant growth and health were made throughout the 2012 season.

Plug plants of *Sidalcea* ‘Party Girl’ were supplied by Barretts Bridge Nurseries (Wisbech, Cambridgeshire, UK) and potted into 9 cm liners in mid-April 2012. Nine centimetre liners of *Ribes* ‘Koja’, *Escallonia* ‘Red Dream’, *Philadelphus* ‘Beauclerk’ and *Choisya ternata* were supplied by New Place Nursery (Pulborough, West Sussex, UK) and *Verbascum* ‘Pink Domino’ was supplied by Howard Nurseries (Diss, Norfolk, UK). During the third week of May 2012, the liners were potted into 3 L pots containing one of the three substrates. Controlled release fertiliser (CRF) (Osmocote Pro 12-14 month, 18+9+10 +2 MgO + trace elements) was incorporated at 3 kg per 1000 L for *Sidalcea* and 5 kg per 1000 L for *Escallonia* and *Ribes*. The bottom 20 mm of compost was gently removed from the liners to leave a root ball of about 60 mm. *Sidalcea* and *Verbascum* floral spikes were removed. Plants were pruned to 16-18 cm (*Ribes*) or 12-13 cm (*Philadelphus*) above soil level; *Escallonia* and *Choisya* plants were not pruned. All plants were placed outside on gravel beds at East Malling Research (EMR) and were hand-watered during five weeks of establishment. At the end of June 2012 following a cold and wet period, plants in peat-free substrate exhibited chlorosis. Analysis of the substrate indicated that insufficient nitrogen mineralisation had taken place, probably due to the weather conditions. On 25 June 2012, plants in peat-free substrate were each given 100 mg nitrogen (applied as 100 mL 6.45 g L^{-1} $CaNO_3$ solution to each pot).

Plants were then placed either on 10 m x 5 m gravel beds (gravel laid over polythene) with overhead irrigation (Figure 1A and B) or on 1 m^2 square plots of mypex overlaying outdoor capillary matting (Lantor, water holding capacity 7 L per m^2) and polythene, on a sand bed measuring 10 m x 5 m on the East Malling Water Centre (EMWC) (Figure 1C). Plants were spaced 8 cm apart, measured between the rims of the pots. Throughout the growing season, flower spikes were removed regularly from *Sidalcea* and *Verbascum* plants.

Figure 1. Experimental plots of *Sidalcea*, *Ribes*, and *Escallonia* plants growing in A) industry standard, B) reduced peat (furthest bed) and peat-free (near bed) substrates receiving overhead irrigation and C) in each of the three substrates receiving sub-surface irrigation. East Malling Water Centre, July 2012.

Experimental design

Plants given overhead irrigation were allocated to one of three 5 m x 5 m experimental beds; different HNS species growing in the same substrate were grouped together on separate beds (Figure 2). Three plots of 16 plants (arranged in a four-by-four plant grid) per crop were randomly distributed within each of four blocks and flanked by two guard rows of *Verbascum*, *Choisya* and *Philadelphus*. The prevailing wind direction on the EMWC was W → E and, therefore, the experimental blocks were arranged to accommodate the likely distribution of overhead irrigation across the beds. Beds 1 and 2 were separated by 0.8 m on a 10 m x 5 m bed. Bed 3 occupied the southern half of a separate 10 m x 5 m bed adjacent to Beds 1 and 2. To allow access for routine measurements, plots were separated in each crop by 0.4 m.

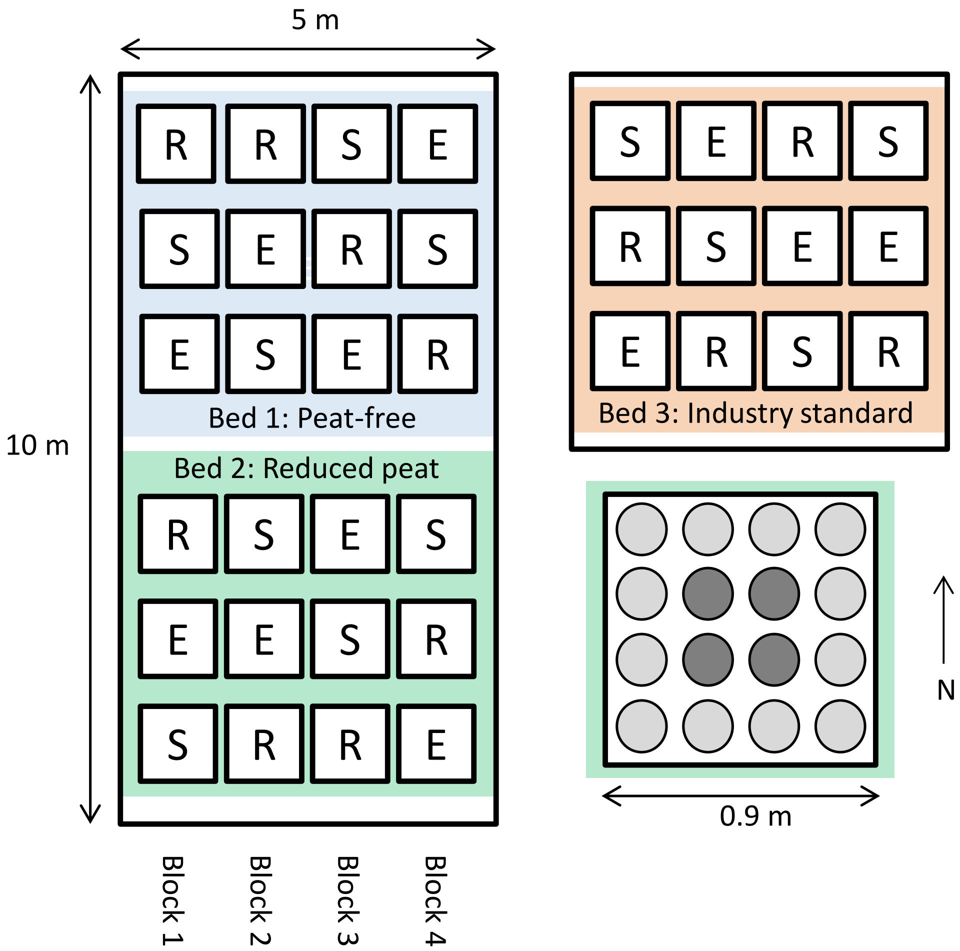

Figure 2. Experimental layout of *Sidalcea* (S), *Ribes* (R), and *Escallonia* (E) plots on each of the three overhead irrigation beds. Plants on each bed were potted in industry standard, reduced peat or peat-free substrate as indicated. Inset: Four experimental plants were chosen within each plot

Plants supplied with sub-surface irrigation were allocated to one of nine experimental plots of sixteen replicate plants (arranged in a four-by-four grid as in Figure 2), which were randomly distributed within each of three blocks aligned north to south (Figure 3). In each plot, there was one of the three HNS species in one of the three substrates. Plots within blocks were separated by 5 cm and adjacent blocks were separated by 0.5 m.

Irrigation application and scheduling

Irrigation was applied automatically using Delta-T SM200 soil moisture probes connected to Delta-T GP1 data loggers (Delta-T Devices Ltd, Cambridge, UK). The soil moisture probes were inserted horizontally through holes drilled in the side of the pots 6 cm below the substrate surface. Preliminary measurements of whole-plant transpiration ensured that the SM200 probes were located in a representative experimental pot for each substrate.

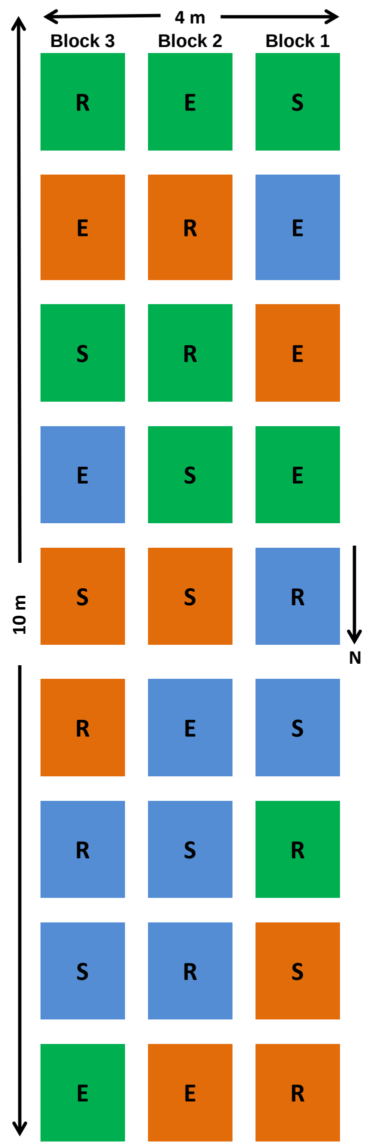

Figure 3. Experimental layout of *Sidalcea* (S), *Ribes* (R), and *Escallonia* (E) plots on the sub-surface irrigation bed. Plants on each plot were potted in Industry standard (blue), reduced peat (orange) or peat-free (green) substrates.

For each irrigation treatment, the timing and duration of irrigation events was controlled using Galcon DC-4S units (supplied by City Irrigation Ltd, Bromley, UK) connected to manifolds housing three DC-4S ¾" valves. Water was sourced from the mains. Overhead irrigation was applied to each bed by six MP rotator 2000 overhead sprinklers spaced 2.5 m apart along the west and east edges of each bed. Sub-surface irrigation was applied using

T-tape irrigation tubing (9.5 mm diameter) supplied via a 3/4" low flow pressure regulator. Each plot was irrigated by two lines of T-tape tubing spaced 60 cm apart, each with six emitters at 15 cm spacing (emitter output specification 0.68 L h^{-1}).

Overhead irrigation distribution patterns and T-tape dripper output were assessed prior to the experiment. Irrigation was set to trigger automatically every hour (overhead beds) and every 15 minutes (sub-surface irrigation bed) to help ensure that pot weights were maintained within the optimal ranges established in Years 1 and 2. To maintain Volumetric Substrate Moisture Content (VSMC) and plant-and-pot weights within the optimal range identified for each crop and substrate, the GP1 irrigation set points were adjusted relative to data obtained from the experimental pots for average soil moisture contents (sub-surface irrigation bed) and average plant-and-pot weights (overhead irrigation beds). Irrigation was scheduled according to the requirements of the crop which was transpiring most freely. Plant-and-pot weights were measured before and after irrigation three times during the growing season and irrigation duration was subsequently adjusted to minimise run-through and water wastage.

Plant growth and physiology

Routine measurements of plant-and-pot weights (for plants given overhead irrigation) and plant physiology were made weekly during the growing season (weather permitting). Transpirational water loss was determined gravimetrically between 09:00 and midday. From the middle of August, to avoid moving pots on the capillary matting bed (and so maintaining the capillary and root contact between the plant pot and the mypex), stomatal conductance was used to monitor physiological responses to the irrigation schedules applied, instead of whole-plant transpiration rates. VSMC was measured using a Delta-T 'WET' sensor. To determine the average VSMC within each pot, four sets of holes were drilled in the sides of each pot to allow the horizontal insertion of the 'WET' sensor probe. The upper sets were drilled 4 cm below the pot 'shoulder' and the lower sets 4 cm up from the pot base. Data were combined from each sampling position to give an average pot VSMC. To minimise disturbance to the root systems and to avoid breaking the capillary action of pots receiving sub-surface irrigation, routine measurements of VSMC were carried out by inserting the WET sensor vertically from the top of the pot, approximately 5 cm in from the rim. Two measurements were made on opposite sides of each pot. There was a high correlation between averages for these measurements and measurements taken through the sides of same pots (data not shown). Between 12:30 and 14:30, stomatal conductance of fully expanded leaves was measured using a leaf porometer (Decagon Devices, USA).

Plant quality

Plant quality in each of the three HNS species was assessed in each substrate by members of the Project Steering Group in May 2013. The four plants in the middle of each experimental block were visually assessed and given a score from 1 to 5. A score of 5 represented excellent quality, 3 was deemed to be acceptable and therefore, marketable, and a score of 1 indicated very poor quality. Representative photos of scores 1 to 5 are shown for *Sidalcea* and *Ribes* in Figures 4 and 5, respectively. Representative photos of scores 2, 3 and 4 are also shown for *Escallonia* (Figure 6); there were no scores of 1 or 5 given to *Escallonia*.

Figure 4. Representative *Sidalcea* plants allocated quality scores by members of the Project Steering Group of 1, 2, 3, 4 and 5 from left to right. Photos taken on 28 May 2013.

Figure 5. Representative *Ribes* plants allocated quality scores by members of the Project Steering Group of 1, 2, 3, 4 and 5 from left to right. Photos taken on 28 May 2013.

Figure 6. Representative *Escallonia* plants allocated plant quality scores by members of the Project Steering Group of 2, 3, and 4 from left to right. Photos taken on 28 May 2013.

Statistical analyses

Statistical analyses were carried out using GenStat 11th Edition (VSN International Ltd.). To determine whether differences between treatments were statistically significant, analysis of variance (ANOVA) tests were carried out and least significant difference (LSD) values for $p \leq 0.05$ were calculated.

Results

Irrigation scheduling to maintain optimum volumetric substrate moisture contents

For overhead irrigation beds, repeated measurements were made during July of VSMC and pot weights for one plant in each plot. For each crop and substrate, linear regression analysis was carried out on a range of values collected for VSMC and plant-and-pot weights (data not shown) and the line of best fit obtained was used to select plant-and-pot weights for scheduling irrigation to maintain the optimal range of VSMC; values for *Escallonia* in each of the three substrates are shown in Table 1. These values are similar to those determined for 3 L pots in year 2, although the pot weight at pot capacity for the reduced peat substrate was lower in year 3; this may have been due to differences in substrate composition between years and/or from different volumes of substrate per pot between the two years, although care was taken to standardise the volume of substrate in each pot. Irrigation to each substrate was scheduled according to the requirements of *Escallonia* which was the crop that transpired most freely. For most substrate / species combinations receiving overhead irrigation or sub-surface irrigation, average plant-and-pot weights were maintained within the optimal ranges identified earlier in the project (Figures 7 and 8).

Table 1. The ranges of average values for VSMC and corresponding plant-and-pot weights for *Escallonia* used for scheduling irrigation to each of the three substrates in 3 L pots. Data are means of four replicate plants.

Substrate	**Optimum plant-and-pot weights and VSMCs for each substrate**			
	Pot weight (g)		**VSMC (m^3 m^{-3})**	
	Pot capacity	**Irrigation set point**	**Pot capacity**	**Irrigation set point**
Industry standard	1907	1600	0.44	0.25
Reduced peat	1774	1450	0.44	0.24
Peat-free	1991	1620	0.41	0.25

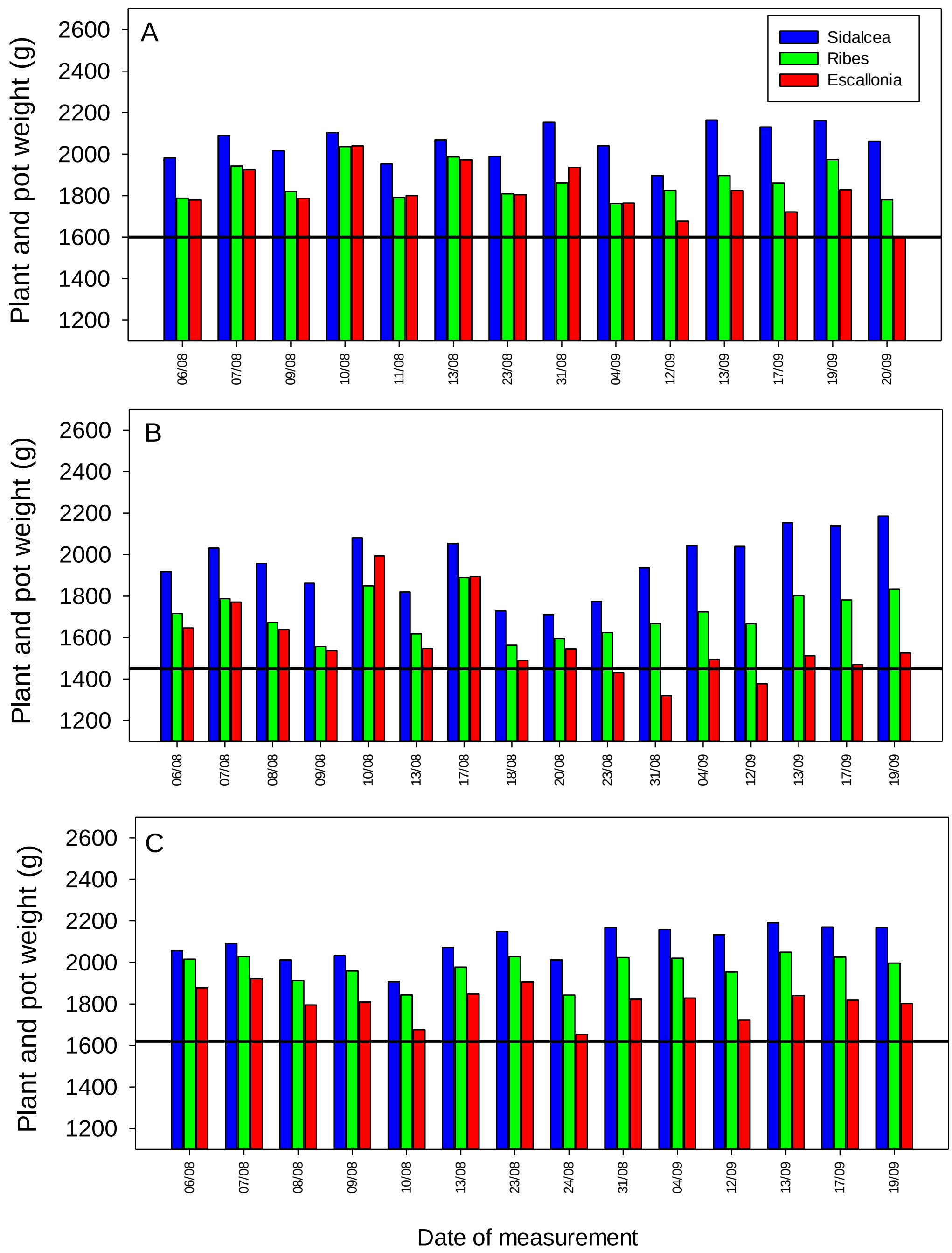

Figure 7. Plant-and-pot weight data for *Sidalcea*, *Ribes* and *Escallonia* plants growing in A) industry standard, B) reduced peat and C) peat-free substrates from August to September 2012. All plants received overhead irrigation. Solid horizontal lines on each graph indicate average plant-and-pot weight at the lower irrigation set point.

At the end of August and early September 2012, the average plant-and-pot weight of *Escallonia* plants receiving overhead irrigation and growing in reduced peat substrate fell below the lower irrigation set point, and approached the value (~1260 g) at which physiological responses to substrate drying are triggered. Monitoring of SM200 and plant-and-pot weight data for the reduced peat substrate over this period indicated that the pot in which the SM200 probe was located was no longer representative of the *Escallonia* crop; therefore, the probe was re-located to another representative pot within the same plot. Similar issues with the *Escallonia* crop in the peat-free substrate receiving sub-surface irrigation resulted in a temporary fall of VSMC below the lower irrigation set point during September 2012 (Figure 8).

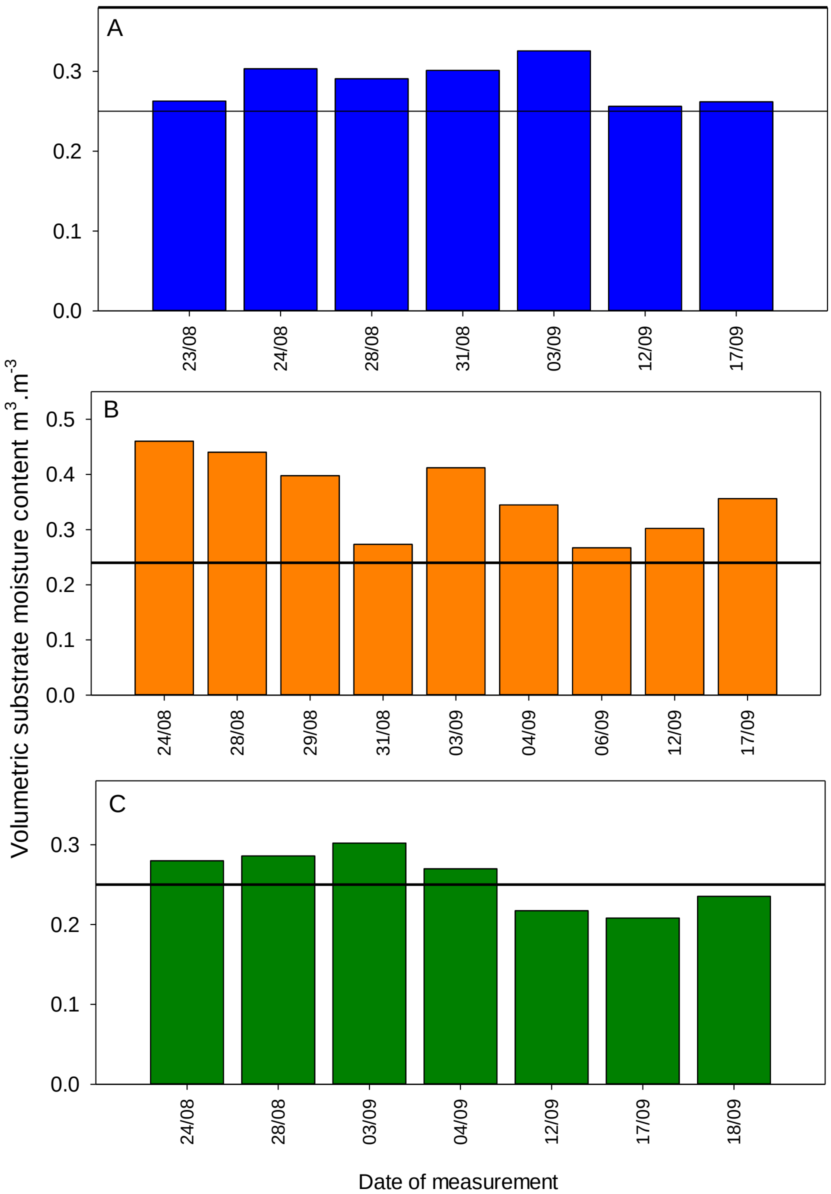

Figure 8. VSMC data for *Escallonia* plants growing in A) industry standard, B) reduced peat and C) peat-free substrates on the sub-surface irrigation bed, for August and September 2012. Solid horizontal lines on each graph indicate the lower set point for each substrate.

Determining irrigation duration and frequency

For each bed with overhead irrigation, irrigation distribution patterns were established by arranging saucers of 17 cm diameter in a grid pattern on each bed. The distance between the saucers was approximately 90 cm W → E and 100 cm N → S. The volume deposited in each saucer during 5 min of irrigation was measured and the rotators were adjusted to optimise irrigation uniformity. The HDC Irrigation Calculator was used to determine mean application rate (MAR) per bed and the coefficient of uniformity, which on a day with almost no breeze was over 82% for each bed (data not shown). Irrigation volumes per pot (18 cm diameter at rim) were calculated from the MAR and the initial irrigation duration was set to deliver the volumes established for each substrate in 2011 (which gave less than 5% run-through). Plant-and/or -pot weights for the central four plants in each plot (except the pots in which the SM200 probes were located) were measured before and after irrigation in June, August and September 2013. The duration of irrigation needed to supply the target volume decreased as the growing season progressed (Table 2); this presumably reflected the greater interception of water droplets and subsequent channelling of water into the pots by the expanding shoot systems.

Table 2. Irrigation duration required to deliver required volumes (giving < 5% run-through in 2011) for each substrate, for each of the overhead irrigation beds in June, August and September 2012.

			Irrigation duration (min) necessary to deliver required volumes		
Substrate	**Irrigation volume required per pot/plant**	**Species**	**Pot only (June)**	**Plant-and-pot (August)**	**Plant-and-pot (September)**
Industry standard	200	*Sidalcea*	29.33	27.04	24.80
		Ribes		22.44	17.04
		Escallonia		22.85	18.77
Reduced peat	100	*Sidalcea*	13.37	11.32	11.29
		Ribes		6.97	7.72
		Escallonia		8.99	7.45
Peat-free	90	*Sidalcea*	12.03	12.65	9.73
		Ribes		9.47	6.30
		Escallonia		8.38	6.74

For each plot receiving sub-surface irrigation, T-tape emitter output over 2 min was measured. Irrigation duration was adjusted to maintain capillary contact between the pot bases and the mypex while avoiding water loss from the edges of each plot. For each substrate, irrigation duration was set to 6 min and during an irrigation ‘window’, which began once the VSMC fell below the lower set point, irrigation was triggered every 15 min until the soil moisture content exceeded the lower set point. During the period from 2 to 11

September 2012, both the frequency of irrigation windows and the number of Irrigation events varied between substrates (Figure 9A-C). Although there were fewer irrigation windows over this period for reduced peat substrate, the average number of irrigation events per irrigation window was higher compared to industry standard and peat-free substrates. It should be noted that the VSMC values measured in the SM200 pot do not necessarily correspond with those in the remainder of the crop (compare VSMC values in Figures 8 and 9), which is acceptable provided that the relationship between the SM200 pot-and-plant and the rest of the crop remains constant. As mentioned above, this is not always the case and the ability to integrate and average readings from multiple moisture probes would help to reduce the risks associated with 'closed loop' irrigation systems (see Discussion).

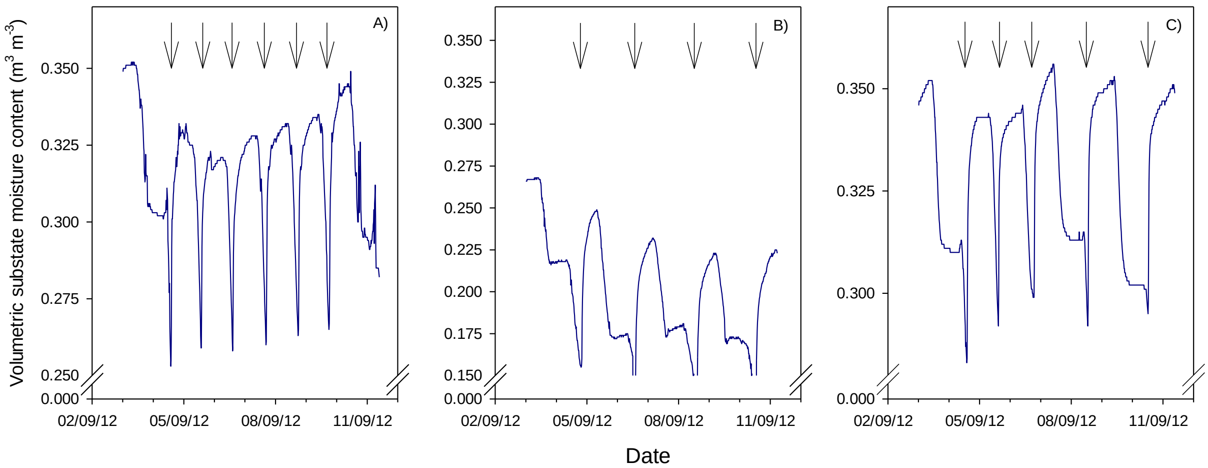

Figure 9. GP1 / SM200 data showing the number of irrigation 'windows' during the period 2 to 11 September 2012, for *Escallonia* plants on the sub-surface irrigation bed growing in A) industry standard, B) reduced peat and C) peat-free substrates. Arrows indicate irrigation events to each substrate.

Irrigation scheduling during periods of heavy rainfall

Scheduling irrigation to uncovered crops following rainfall events is difficult for HNS growers due to the uncertainty over how much of the rain fell onto the substrate surface, or how much was intercepted by the canopy and channelled into the pot. In the HNS industry, 5 mm of rainfall or more is generally considered to be 'effective rainfall' i.e. sufficient to raise VSMCs. However, it is difficult for growers to decide when to resume irrigation following 'effective rainfall', especially if the weather continues to be changeable. The automated irrigation system used in conjunction with the lower irrigation set points developed in this project effectively removes the uncertainty following rainfall events; this system prevented over-irrigation of the HNS crops during the very wet summer of 2012.

Plant growth and physiology

Measures of whole-plant transpiration and stomatal conductance were made at intervals throughout the season to establish whether the 'optimum' substrate water contents allowed plants to transpire freely under different evaporative demands. For plants given overhead irrigation, whole-plant transpiration rates were measured throughout the experiment; and although significant differences between plants in the different substrates were noted on several occasions (Figure 10), there were no consistent trends. The lower transpiration rates measured in the reduced peat substrate on 31 August and 4 September 2012 were due to the low VSMCs in the *Escallonia* plants caused by the issues noted above with the SM200 probe. Data collected on 23 August and 4 September for peat-free and industry standard substrates respectively, were unreliable and have therefore been omitted. For plants receiving sub-surface irrigation, transpiration was measured during July and early August and although significant differences were seen on some dates between substrates (Figure 11A), these most likely reflected differences in canopy sizes between plants in different substrates. This view is supported by measurements of stomatal conductances from early August onwards which showed no significant substrate effects (Figure 11B); this suggests that plants were transpiring freely and that substrate water availability was not limiting under the irrigation regimes imposed.

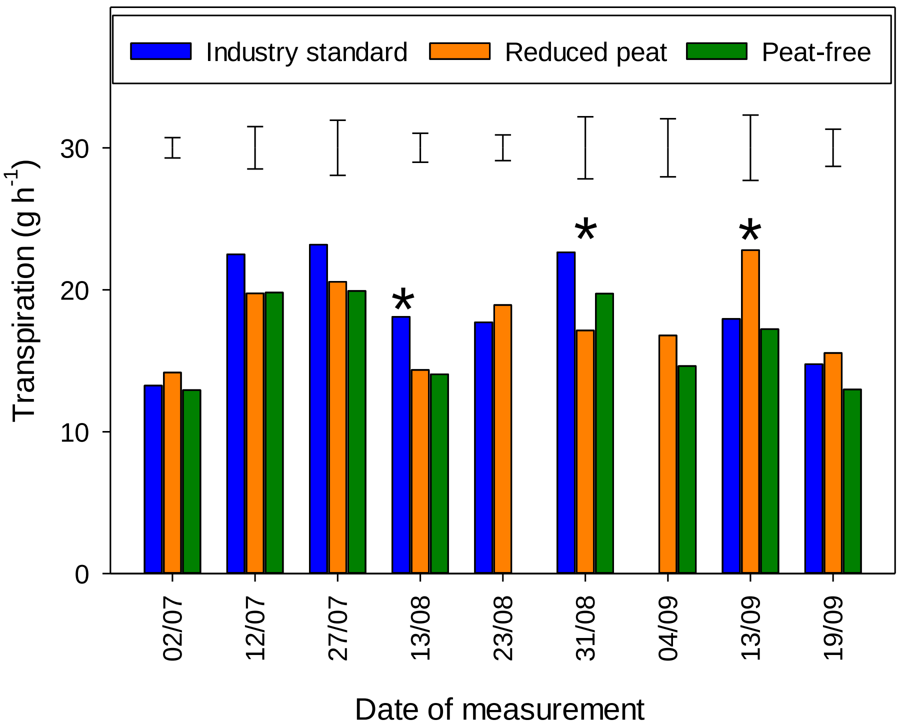

Figure 10. Whole-plant transpiration rates averaged for *Sidalcea, Ribes* and *Escallonia* in each of the three substrates at intervals over the 2012 growing season. All plants received overhead irrigation. Vertical bars are LSDs *p*<0.05; asterisks indicate statistically significant differences between substrates.

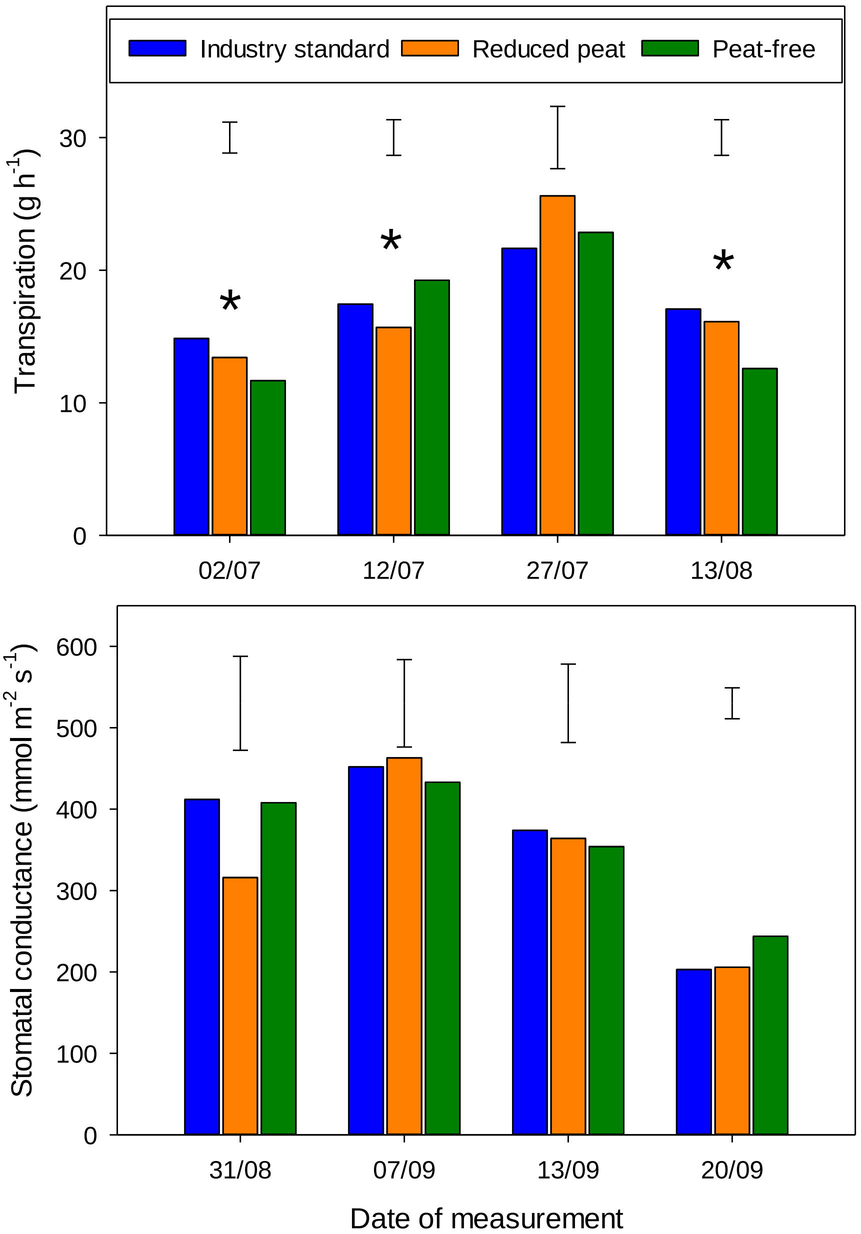

Figure 11. A) Whole-plant transpiration rates and B) stomatal conductances averaged for *Sidalcea, Ribes* and *Escallonia* growing in each of the three substrates at intervals over the 2012 growing season. All plants received sub-surface irrigation. Vertical bars are LSDs $p<0.05$; asterisks indicate statistically significant differences between substrates.

Plant quality

At the end of June 2012 following a cold and wet period, plants in peat-free substrate were exhibiting signs of chlorosis. Analysis of the substrate indicated that insufficient nitrogen mineralisation had taken place, probably due to the weather conditions. Therefore, plants in peat-free substrate were each given 100 mg nitrogen (applied as 100 mL 6.45 g L^{-1} $CaNO_3$

solution to each pot) on 25 June 2012.

Estimates of overall plant quality made by members of the Project Steering Group in May 2013 indicated that there were no significant effects of the three substrates on plant quality scores in the overhead irrigation treatment (Table 3).

Table 3. Assessment of plant quality for each species in each substrate and each species receiving overhead irrigation; estimates were made on 16 May 2013.

Plant species	Plant quality score*			
	Industry standard	Reduced peat	Peat-free	Average
Sidalcea	3.2	3.1	3.5	3.3
Ribes	3.8	3.6	3.4	3.6
Escallonia	3.8	4.0	3.8	3.8
Average	3.6	3.6	3.6	

* 1 = very poor; 2 = poor; 3 = marketable; 4 = very good; 5 = excellent

When sub-surface irrigation was applied (*via* capillary matting), plant quality of *Escallonia* grown in the reduced peat substrate was reduced compared to plants in the peat-free and industry standard substrates, although this effect was just outside statistical significance (Table 4). The quality of *Sidalcea* and *Ribes* was similar in each of the three substrates.

Table 4. Assessment of plant quality* for each species in each substrate and each species receiving sub-surface irrigation; estimates were made on 16 May 2013.

Plant species	Plant quality score*			
	Industry standard	Reduced peat	Peat-free	Average
Sidalcea	3.3	3.6	3.7	3.5
Ribes	3.4	3.8	3.4	3.6
Escallonia	3.8	3.2	3.7	3.6
Average	3.5	3.5	3.6	

* 1 = very poor; 2 = poor; 3 = marketable; 4 = very good; 5 = excellent

Moss and liverwort coverage was assessed separately on a 6-point scale, 0 (none), 1 (1-20%), 2 (21-40%), 3 (41-60%), 4 (61-80%) and 5 (81-100%). Moss coverage was, perhaps not surprisingly, lower in the pots receiving sub-surface irrigation than those receiving irrigation overhead (data not shown). However, in both irrigation systems, moss coverage was significantly higher in pots of *Sidalcea* and in plants in the peat-free substrate (Table 5); however, the substrate: species interaction was not quite statistically significant (P = 0.054). Moss coverage in *Ribes* and *Escallonia,* and in industry standard and reduced peat substrates, were similar (Table 5).

Table 5. Estimates of the percentage surface cover* of mosses for each substrate and each species receiving overhead irrigation; estimates were made on 16 May 2013. Asterisks indicate a statistically significant difference ($P < 0.05$) between substrates, $^{+}$ indicate a statistically significant difference ($p < 0.05$) between species.

Plant species	**Moss coverage**			
	Industry standard	**Reduced peat**	**Peat-free**	**Average**
Sidalcea	1.2	2.6	3.8	2.5^{+}
Ribes	0.3	0.5	1.6	0.8
Escallonia	0.5	0.1	0.1	0.2
Average	0.7	1.1	1.8*	

	***P*-Value**	**LSD**
Substrate	0.02	0.80
Species	<0.001	0.80
Substrate.Species	0.054	1.40

* 0 = 0%, 0.1 to 1 = 1 to 20%; 1.1 to 2 = 21 to 40%; 2.1 to 3 = 41 to 60%; 3.1 to 4 = 61 to 80%; 4.1 to 5 = 81 to

Under the overhead irrigation system, the levels of liverwort were significantly higher in pots containing Sidalcea, very little liverwort was recorded in *Ribes* and *Escallonia* (Table 6). Liverwort levels were low and similar in all three substrates (Table 6). Under the sub-surface irrigation regime, there were no differences in the incidence of liverworts between the three substrates or the three species (data not shown).

Table 6. Estimates of the percentage surface cover* of liverworts for each substrate and each species receiving overhead irrigation; estimates were made on 16 May 2013. Asterisks indicate a statistically significant difference ($p < 0.05$) between substrates for each species, $^{+}$ indicate a statistically significant difference ($P < 0.05$) between species.

Plant species	**Moss coverage**			
	Industry standard	**Reduced peat**	**Peat-free**	**Average**
Sidalcea	1.1	0.8	0.3	0.7^{+}
Ribes	0.3	0	0	0.1
Escallonia	0	0	0.1	0
Average	0.5	0.3	0.1	

	***P*-Value**	**LSD**
Substrate	0.127	0.17
Species	0.001	0.17
Substrate.Species	0.251	0.29

* 0 = 0%, 0.1 to 1 = 1 to 20%; 1.1 to 2 = 21 to 40%; 2.1 to 3 = 41 to 60%; 3.1 to 4 = 61 to 80%; 4.1 to 5 = 81 to 100%

Qualitative estimates of the proportion of the substrate volume occupied by roots suggested that the root mass of *Sidalcea* and *Escallonia* were similar in the three substrates (data not shown but that rooting of Ribes was more extensive in industry standard substrate, compared to the peat-reduced and peat-free substrates. These differences in rooting propensity did not, however, affect overall plant quality at simulated market date.

To demonstrate the wider relevance of the irrigation regimes, the Project Steering Group suggested that the crops *Verbascum*, *Choisya ternata* and *Philadelphus* were used as guard rows on beds with overhead irrigation. These crops were chosen as their irrigation requirements are similar to those of *Sidalcea*, *Ribes* and *Escallonia*, respectively. These plants were not assessed but general observations of plant growth and health made throughout the 2012 season indicated that the irrigation scheduling regimes were also appropriate for these species when grown in each of the three substrates tested.

Discussion

The overall aim of the project was to develop and implement improved irrigation scheduling guidelines for reduced peat, peat-free and industry standard media that would help growers comply with legislation, optimise plant quality, reduce costs and gain confidence in growing HNS in peat alternatives. Trickle/drip irrigators have so far been exempt from Water Framework Directive legislation and it is now anticipated that trickle/drip irrigation will be brought under legislation from April 2014. There will be increasing pressures on growers to comply with the guidelines administered by the Environment Agency and all growers will have to demonstrate an efficient use of irrigation water to secure their abstraction licences. Much work on irrigation scheduling has been carried out for HNS (*e.g.* HortLINK 97, 97b[5], HNS 122[6], HNS 141) and the associated factsheets should offer useful advice on how improvements in on-nursery water use efficiencies can be achieved. The exemplary work carried out by Charles Carr and colleagues at Lowaters Nursery (which won the UK Water Efficiency Award in 2012), serves as an example of what can be achieved in commercial HNS production. Nevertheless, more translational work is needed to help the majority of HNS growers to implement and maintain water- and fertiliser-saving irrigation strategies that also optimise plant quality.

In this project, the 'optimum' substrate moisture content is defined as one that supports good, healthy plant growth while avoiding over-wet conditions so that leaching of irrigation water and fertilisers is minimised or eliminated. To identify the optimum range of substrate moisture contents, our approach was to first determine VSMC at 'pot capacity' then impose gradual substrate drying on half of the plants and monitor physiological responses such as stomatal conductance, transpiration rate and leaf extension growth. In year 1, the plant- and pot-weights (2 L pots) and the range of VSMCs at which several physiological responses to limited substrate water availability were triggered in each of the three substrates were identified for *Sidalcea, Ribes* and *Escallonia*. The plant- and pot-weight 24 h before the first physiological response in each species was triggered was taken as the lower irrigation set point for that substrate. In year 2, the lower irrigation set points for each of the three substrates were imposed on the three HNS species using drip irrigation in experiments on the EMWC to determine whether the 'optimum' range of moisture contents developed in this project enabled all plants to transpire freely and promoted strong healthy plant growth of sufficient quality for the HNS industry. The main aim of the work in the third project year was to schedule overhead and sub-surface irrigation to three HNS crops on the EMWC, using the optimum ranges of VSMC for reduced peat, peat-free and industry standard media identified in year 1.

Plant physiological measurements conducted over the growing season confirmed that the optimal range of VSMC developed in this project enabled the three HNS species tested to transpire freely since physiological responses to limited substrate water availability were, generally, not detected. Significant differences in transpiration were noted in each crop on some dates during the growing season, but in most cases, this was likely due to the variation in plant canopy leaf area in the different substrates. With the exception of the reduced peat substrate during early September, there was no evidence that physiological responses to limited substrate availability were triggered in the three HNS species growing in each of the three substrates. These irrigation set points have been developed for the three HNS species tested under growing conditions typical of the UK climate; irrigation set points for other species and for hotter, drier climates where daily ET can reach 6-7 mm per day will need to be developed and tested in further work.

Plant quality at simulated dates of sale was similar for each of the three HNS species growing in each of the three substrates when supplied with overhead (Table 3) or sub-surface irrigation (Table 4). The results suggest that provided irrigation is scheduled effectively, there are no significant differences in quality between plants grown in the current industry standard substrate and the peat-reduced and peat-free substrates used in our experiments. Similar results were obtained for *Sidalcea* plants in Year 2. However, the availability of essential macro- and micro-nutrients in the three substrates was not addressed in this project and further work will be needed to determine the optimum fertiliser requirements of HNS plants in reduced peat and peat-free media. In our work, an industry standard rate of CRFs was added to each substrate but plants in the peat-free substrate appeared chlorotic following a wet and cold period in June 2012. Analysis of the substrate indicated that insufficient mineralisation had occurred and so supplemental nitrogen was given.

Although plant quality was unaffected by reduced peat or peat-free substrates, moss coverage was significantly higher in *Sidalcea* and in the peat–free substrate. Although the interaction between substrate and species was not quite significant, the trend was that moss coverage was highest in *Sidalcea* growing in peat–free substrate (Table 5) with an estimated 80% pot surface coverage in the worst cases. Liverworts were also more prevalent in the peat-free and peat reduced media compared to the industry standard, although coverage was below 20% and the differences were not statistically significant. This result was unexpected since previous reports had shown moss and liverwort coverage to be lower on peat free substrates due to their generally drier surface. This may have arisen from a wetter substrate surface caused by more frequent irrigation events applied to maintain the optimum VSMC and to limit run-off in the peat-free substrate in our experiments.

As in 2011, irrigation was again scheduled to each species in each of the substrates during the 2012 growing season using Delta-T SM200 moisture probes connected to GP1 data loggers. This system was used with great success at Hillier Nurseries Ltd in HortLINK 97b; water savings of 80% were achieved over the season, compared to plants where irrigation frequency and duration were decided by Hillier staff. The automated irrigation system used in conjunction with the lower irrigation set points developed in this project was particularly effective during the rainy 2012 growing season since any uncertainty about whether rainfall events were effective or not was removed and the system prevented over-irrigation of the HNS crops during the very wet summer of 2012. New tools and technology are needed to help improve on-farm decision making and the automated 'closed loop' irrigation system used here could help growers to improve their water use efficiency and reduce run-through of water and fertiliser. However, it would be risky to schedule irrigation to blocks of high-value HNS crops using a system that relies on the output from a single moisture probe. In our experiment with *Escallonia* in reduced peat and peat-free substrates, the SM200 probe was located in a pot that gradually became unrepresentative of the rest of the crop, with the result that the plant-and pot weight and VSMC values fell, albeit temporarily, below the irrigation set points. In scientific experiments, this limitation can now be overcome by using the new Delta-T GP2 Advanced Datalogger and Controller which can average values from up to 12 different moisture probes. This system is being used with great success in on-going strawberry experiments at EMR and plans are afoot to establish wireless communication with the GP2 and commercial irrigation/fertigation rigs so that the system can be integrated into high-value commercial substrate strawberry production. Whether such a 'closed loop' system would be cost-effective for medium to large HNS growers remains to be seen. Straightforward plant-and-pot weighing could also be used to schedule irrigation effectively on small- to medium-sized nurseries, and irrigation scheduling in response to evaporative demand is already being practised by a few progressive HNS growers.

Probes that measure the VSMC have been used in this project to determine and maintain lower irrigation set points in each of the three substrates. Other research groups are also using this approach to develop water-saving irrigation scheduling regimes for HNS crops[7]. Although these measurements, when combined with a detailed knowledge of plant physiology, provide useful information on the optimum range of substrate moisture contents, they are influenced by differences in substrate bulk density and so it is likely that the absolute values will change as substrates settle or slump during the growing season. Whilst these numeric changes may be relatively minor and therefore impact very little on irrigation scheduling, it would be preferable to base irrigation scheduling on substrate matric potential, as this value is not influenced by changes in substrate bulk density. Matric potential is a measure of water availability and this is likely to differ in substrates with different percentages of peat content. Hitherto, this has not been possible due to the lack of suitable matric potential probes for use in substrates. However, Delta-T Devices Ltd and EMR have recently completed a TSB project in which a foam-based matric potential was developed and tested in coir. There is great potential to use this new sensor in conjunction with the GP2 to achieve multi-zone irrigation control based on changes in substrate matric potential; this is currently being tested in coir-grown strawberry at EMR.

Most growers acknowledge that irrigation and nutrient regimes will need to be modified when using reduced peat and peat-free substrates. The relatively poor water-holding capacity of most peat-free alternatives will necessitate more frequent irrigation events but over-watering must be avoided to minimise run-through of water and dissolved fertilisers and limit environmental pollution. The water holding capacity for each substrate was estimated by measuring the duration of irrigation that resulted in less than 5% run-through when the plant-and-pot weight was at the lower irrigation set point. As anticipated, water-holding capacity was 30-50% less in peat-free substrate than industry standard substrate (HNS 182 Annual Report 2012, Table GS2). Water-holding capacity was consistent between crops for industry standard substrate, but varied with crop for plants growing in reduced peat and peat-free substrates. This may have been due to differences in root development in the different crops resulting in more open, more freely draining substrates. For each crop, plants growing in peat-free substrate required more frequent irrigation then those growing in industry standard and peat-reduced substrates.

This project has demonstrated that, provided irrigation is scheduled effectively, yields and quality of the three HNS species tested can be maintained in reduced peat and peat-free substrates. Problems of poor water holding capacity and the need for more frequent and careful irrigation scheduling with peat-free mixes has led to the view that peat-free crops are more difficult to look after, both on the nursery and during retailing, and this has slowed industry uptake. The results from this project should help to increase grower confidence in reduced peat and peat-free substrates and will hopefully provide an insight into how current irrigation scheduling systems would have to be adjusted to accommodate shorter and more frequent events. Trickle / drip irrigation is to be brought into the abstraction licencing legislation in April 2014. HNS growers will then face increasing pressure to use water more efficiently and the guidelines developed in this project should help growers to schedule irrigation effectively to industry standard, reduced peat and peat-free media to ensure that yield and quality are maintained or improved. An HDC factsheet will be prepared to help facilitate grower uptake of the approaches developed in this project.

The HNS industry's views on peat replacement and peat alternatives are set out in the HDC News Growing Media Review which also highlights research into growing media funded by the HDC and other agencies and discusses the remaining barriers to further reduction or elimination of peat in substrates for commercial growers. On this latter point, the message is that although many growers have voluntarily reduced the peat content of their growing media in recent years, there is little commercial incentive or legislative pressure to reduce peat contents further. For as long as this continues, the Review concludes that peat will remain the industry's staple growing medium.

Main Conclusions

- Plant-and-pot weights and VSMC were highest at pot capacity in the Industry standard substrate
- VSMC values at which plant physiological responses are triggered were identified for *Sidalcea*, *Ribes* and *Escallonia* grown in industry standard, reduced peat and peat-free substrates
- VSMC at which physiological responses to drying substrate varied according to crop and substrate
- The 'optimum' range of VSMC and plant-and-pot weights in each substrate were determined for *Sidalcea, Ribes and Escallonia* and maintained throughout two growing seasons using drip irrigation, overhead irrigation and sub-surface irrigation

- Water holding capacity of substrates was 30-50% less in peat-free substrate than industry standard substrate and the water holding capacity in peat-reduced and peat-free substrates varied with crop
- Irrigation frequency was higher for crops growing in peat-free substrate compared to plants growing in industry standard and reduced peat substrates
- Plant growth and quality in peat-free and reduced peat substrates were similar to those in industry standard substrate, when irrigation scheduling was optimised
- The occurrence of mosses and liverworts on the surface of the substrate was greatest for *Sidalcea* receiving overhead irrigation
- Moss coverage was greatest on the surface of the peat-free substrate under overhead irrigation
- An automated irrigation scheduling tool that has previously been tested on commercial nurseries in HortLINK 97b experiments was used to maintain 'optimum' VSMCs under drip, overhead and sub-surface irrigation
- The automated irrigation scheduling tool prevented over-irrigation of plants during the heavy and frequent rainfall in 2012
- The approaches developed in this project could be used to identify the optimum range of substrate moisture contents in a range of sustainable growing media

Knowledge exchange and Technology Transfer

- An article summarising the project aims and objectives and results to date was published in the May 2012 edition of HDC News
- Meetings with the Project Steering Group were held throughout the project to discuss approaches and finalise experimental plans, discuss results, view on-going trials and plan knowledge exchange and technology transfer events The project aims and objectives were discussed with Dr Paul Alexander during a visit by EMR project staff to RHS Wisley to view on-going peat alternative trials
- The methodologies used to determine the optimum range of moisture contents were discussed with Dr Paul Alexander and Nick Morgan (RHS Wisley) during a visit on 2 March 2011 to view the trials at EMR
- The project aims, objectives and results to date were presented at an HDC HNS Irrigation Optimisation Day held at EMR on 15 August 2012
- The project aims, objectives and results to date were presented at an IPPS International Conference held at EMR on 27 September 2012
- The project aims, objectives and results were presented at the HDC Herbaceous Perennials Technical Discussion Group Summer Nursery Meeting on 10 July 2013.

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References

1) Waller, P. (2006). A review of peat alternatives for commercial plant production in the UK. Horticultural Development Company Final report for project CP 41
2) Noble, R. (2006). Hardy Ornamental Nursery Stock: Waste into rooting media (WIRM). Horticultural Development Company Final report for project HNS 127.
3) http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenvfru/492/49211.htm
4) Larcher, F. and Scariot, V. (2009). Assessment of Partial Peat Substitutes for the Production of Camellia japonica. *HortScience* 44: 312-316
5) Grant, O.M. *et al.* (2007). Container Nursery Stock Irrigation: Demonstration and Promotion of Best Practice. Horticultural Development Company Final report for project HNS 122.
6) Davies, W.J. *et al.* (2009). Enhancing the quality of hardy nursery stock and sustainability of the industry through novel water-saving techniques. Horticultural Development Company Final report for project HNS 97b.
7) Incrocci, L *et al.* (3013). Scheduling irrigation in heterogeneous container nursery crops. Conference Proceedings of the International Symposium on Growing Media and Soilless Cultivation, Wageningen, June 2013.

