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:	Annual Report, March 2012
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Location of project:	East Malling Research
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Date project commenced:	1 April 2010
Date project completed (or expected completion date):	31 March 2013

DISCLAIMER:

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.

Fiona Wilson
Project Manager
East Malling Research

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GROWER SUMMARY

Headline

- Irrigation was scheduled successfully to three HNS crops using the optimum range of substrate water contents developed for reduced peat, peat-free and industry standard media
- Irrigation frequencies and durations that maintained optimum substrate water contents were identified for each substrate
- An automated irrigation scheduling tool was developed for use on commercial nurseries
- Plant quality in the different substrates was similar

Background and expected deliverables

The HNS sector is the largest user of peat in the UK horticultural industry. 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. Although some customers request peat-free production (*e.g*. The National Trust), the majority do not, and so at the moment there is little commercial pressure to reduce peat use. Following a consultation period (ending 11th March 2011), Defra has outlined plans to reduce the horticultural use of peat in England in the Natural Environment White Paper published June 2011. This includes a voluntary phase-out target of 2030 for professional growers of fruit, vegetables and plants. The proposed withdrawal of peat from the UK horticulture industry is of great concern to many HNS growers.

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. To help facilitate the development of 'best' or 'better' grower practice during the transition to peat-free production, new scientifically-derived irrigation set points 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 will be used to develop new guidelines to help growers overcome problems associated with over-watering reduced peat and peat-free alternatives.

The overall aim of the project is to develop and implement improved irrigation scheduling guidelines for reduced peat, peat-free and industry standard media that 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

Experimental plant species and commercially available reduced peat, peat-free and industry standard substrates were selected after consultation with members of the Project Steering Group. The following widely-produced crops were chosen for 2011 experiments as they were considered moderately resilient to substrate drying and therefore a good choice of 'indicator' species:

- *Ribes sanguineum* 'Koja'
- *Escallonia rubra* 'Crimson Spire'
- *Sidalcea* 'William Smith'

The following substrates were chosen (for use in years 1 and 2) since they are considered to be good quality brands that are (or are becoming) widely used by UK growers:

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

Specification details were obtained for each substrate; additionally each was analysed for air-filled porosity, particle size distribution, pH, density, dry matter, dry density, Ca, Cl, Mg, P, K, Na, N, EC and trace elements[8].

Nine centimetre liners were potted in to 3 L pots containing one of the three substrates. The bottom 20 mm of compost was gently removed to leave a root ball of about 60 mm. Controlled release fertiliser (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*. All plants were established under cover in an unheated mesh-walled polytunnel and were hand-watered during establishment.

Plants were then placed on a mypex bed (mypex over polythene) on the East Malling Water Centre (EMWC) (Figure GS1). *Sidalcea* plants were cut back to approximately 5 cm above soil level; *Ribes* were cut back to just above the height at which the stems had previously been pinched, *i.e.* between 18 cm and 26 cm, and *Escallonia* were trimmed to approximately 22 cm. *Sidalcea* and *Escallonia* plants were cut back once more during the experiment and *Sidalcea* plants were cut back at the end of the growing season.

Figure GS1. Experimental plots of *Sidalcea*, *Ribes* and *Escallonia*, East Malling Water Centre, July 2011.

One aim of this project is to develop a practical irrigation scheduling tool for use on commercial nurseries. Delta-T Devices, (Cambridge, UK) supply a data logger capable of switching solenoid valves on and off when a soil moisture probe detects changes in volumetric soil moisture content (VSMC). In HortLINK project 97b, water savings of 80% were delivered over the season at Hillier Nurseries Ltd when irrigation was scheduled using Delta-T SM200 soil moisture probes connected to a GP1 data loggers, compared to plants where irrigation frequency and duration were decided by Hillier staff. Savings in staff time were also achieved by reducing the time taken deciding whether or not to irrigate. This system has also been used to schedule irrigation and deficit irrigation regimes to poinsettia crops on a commercial nursery. Since the Delta-T GP1/SM200 system has already been implemented successfully on commercial nurseries, it was chosen to schedule irrigation to each species in each of the substrates in experiments on the EMWC during the 2011 growing season. This system may be particularly suited to reduced-peat and peat-free substrates since positioning the probe below the layer that tends to dry out would ensure that irrigation is triggered in response to changes in the VSMC in the rooting zone, rather than the top layer of the substrate. Due to the different water-holding capacity of reduced peat and peat-free substrates, the VSMCs at which irrigation should be triggered will differ from those already established for 100% peat. Straightforward plant-and-pot weighing could also be used to schedule irrigation effectively on smaller to medium size nurseries. The frequency and duration of irrigation events will also need to be adjusted to limit run-through when using more freely draining peat alternatives.

Water was sourced from the mains and irrigation to each pot was supplied *via* a dripper stake and bootlace connected to a pressure compensated 2 L h^{-1} emitter. For each crop the timing and duration of irrigation events was controlled using three Galcon DC-4S units (supplied by City Irrigation Ltd, Bromley, UK) connected to manifolds housing three DC-4S ¾" valves. To maintain VSMC and plant-and-pot weights within the optimal range identified in year 1 for each crop and substrate, the GP1 irrigation set points were adjusted frequently to ensure that average VSMC and average plant-and-pot weights were maintained in the experimental plants. The duration of each irrigation event was adjusted to ensure that run-through was minimised.

Experiments in year 1 were carried out using 2 L pots but the Project Steering Group recommended that 3 L pots were used in 2011. Therefore, the optimum range of plant-and-pot weights for 3 L pots was determined for each substrate, along with corresponding VSMC values (Table GS1).

Table GS1. The ranges of average values for VSMC and corresponding plant-and-pot weights used for scheduling irrigation of *Sidalcea*, *Ribes* and *Escallonia* plants grown in each of the three substrates in 3 L pots. Data are means of eight replicate plants.

A) *Sidalcea*

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
Sinclair	2052	1420	0.46	0.23
Bulrush	2096	1540	0.49	0.34
Vital Earth	2106	1680	0.41	0.29

B) *Ribes*

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
Sinclair	1998	1400	0.48	0.29
Bulrush	2010	1230	0.46	0.22
Vital Earth	2069	1620	0.41	0.3

C) *Escallonia*

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
Sinclair	1995	1471	0.44	0.25
Bulrush	2041	1450	0.44	0.24
Vital Earth	1955	1545	0.41	0.25

Rates of substrate drying were low in *Ribes*, and so to enable a comparison of irrigation frequency and duration to be made between substrates, the VSMC irrigation set points were raised for Sinclair and Bulrush substrates.

The water holding capacity for each substrate was estimated by measuring the irrigation duration 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 (Table GS2).

Table GS2. Frequency of irrigation and total irrigation volumes applied between 27 September 2011 and 1 October 2011, over 430 accumulated degree hours (*Sidalcea*), 369 accumulated degree hours (*Ribes*) and 335 accumulated degree hours (*Escallonia*), for plants grown in each of the three substrates. For *Sidalcea, Ribes* and *Escallonia* plants growing in Vital Earth substrate values are means of eight replicate plants; for *Ribes* plants growing Bulrush and Sinclair substrates, values are means of seven and four replicate plants, respectively. Volume of run through has been deducted to derive values for total volume applied.

A) *Sidalcea*

Substrate	Lower pot weight	Irrigation volume giving ≤5% run-through	Number of irrigation events	Mean total volume applied (ml)
Sinclair	1420	207	2	409
Bulrush	1540	205	2	402
Vital Earth	1680	134	4	539

B) *Ribes*

Substrate	Lower pot weight	Irrigation volume giving ≤5% run-through	Number of irrigation events	Total volume applied (ml)
Sinclair	1400	192	2	370
Bulrush	1230	102	2	200
Vital Earth	1620	94	4	367

C) *Escallonia*

Substrate	Lower pot weight	Irrigation volume giving ≤5% run-through	Number of irrigation events	Total volume applied (ml)
Sinclair	1580	202	3	585
Bulrush	1450	189	3	537
Vital Earth	1545	90	6	529

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.

To help ensure that the optimum ranges identified for each substrate did not affect plant growth and quality, plant physiological and growth measurements were made during the growing season. Transpirational water loss, stomatal conductance and leaf growth were monitored frequently at regular intervals, as these were shown in year 1 to be sensitive indicators of substrate drying. For each crop, no significant differences were detected between substrates in stomatal conductance and leaf growth, indicating that the plants were transpiring freely and that the upper and lower irrigation set points were optimal. Although significant differences in transpiration and evapo-transpiration between substrates were seen in all crops on some dates (Figure GS2), the absence of significant differences in stomatal conductances imply that differences in plant canopy leaf area were the cause. When significant differences were noted, rates of evapo-transpiration per degree hour of *Sidalcea* plants were often greater in the reduced-peat and peat-free substrates than in the industry standard substrate. In contrast, rates of evapotranspiration per degree hour were reduced for *Escallonia* plants growing in peat-free substrate during September 2012.

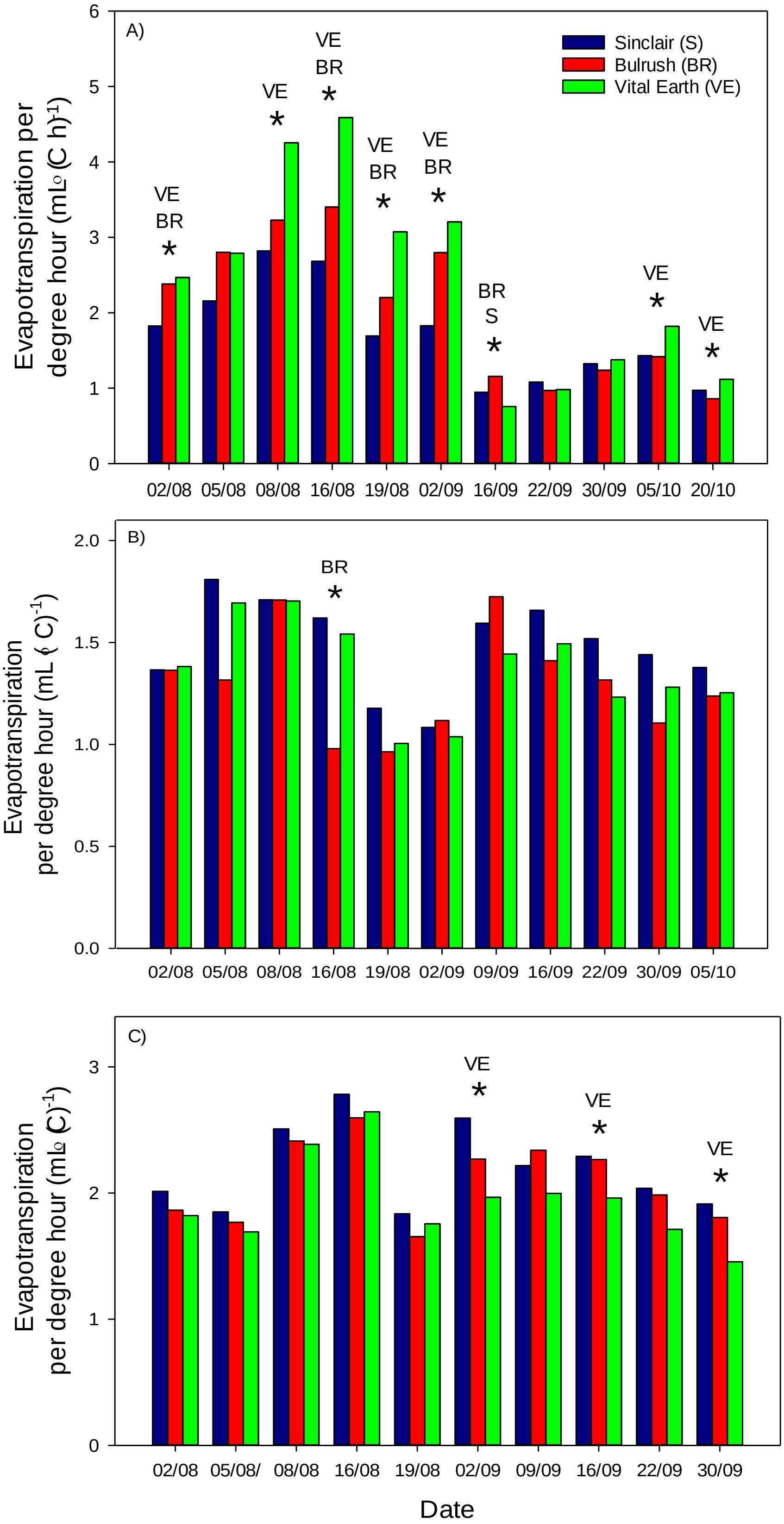

Figure GS2. Statistically significant differences in evapotranspiration rates of A) *Sidalcea* B) *Ribes* and C) *Escallonia* grown in industry standard (Sinclair), reduced peat (Bulrush) and peat-free (Vital Earth) substrates

Average plant grade-out at simulated dates of sale was similar for *Sidalcea* plants growing in peat-free, reduced peat substrates, and industry standard substrates (Figure GS3). This suggests that the upper and lower irrigation set points derived for the three substrates would be suitable for the commercial production of *Sidalcea*. The quality of *Sidalcea, Ribes* and *Escallonia* in each of the three substrates will be determined in Spring 2012 and the results will be presented in the Final Report.

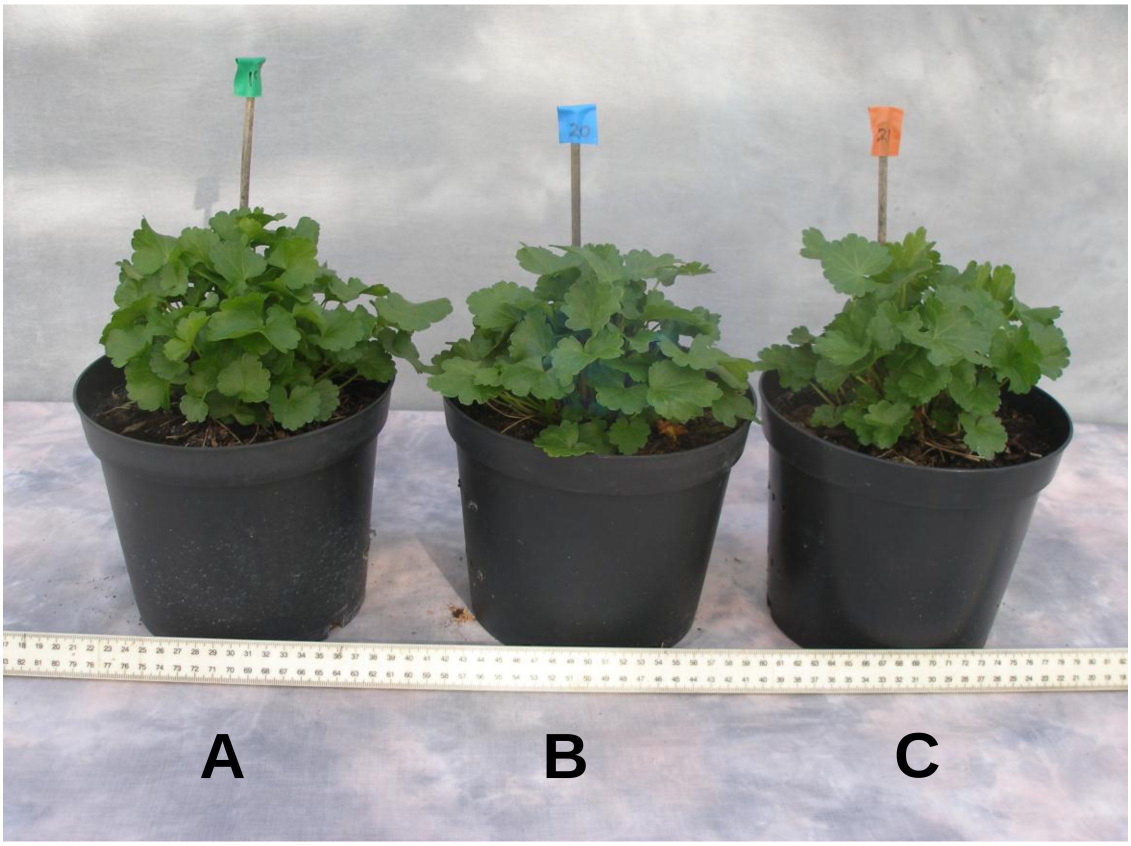

Figure GS3. *Sidalcea* plants graded as saleable at simulated date of sale, growing in A) peat-free (Vital Earth); B) industry standard (Sinclair) and C) peat-reduced (Bulrush) substrates.

Plants on the EMWC were over-wintered and measurements of pot weights and VSMC were made to determine whether the more freely draining reduced peat and peat-free substrates were less prone to waterlogging. In March 2012, samples were taken of each substrate from over-wintered pots of each crop, and values for air filled porosity obtained; these values will be published in the Final Report. Visual inspections of root and canopy health will be carried out in Spring 2012 to determine whether plant vigour is improved in the more freely-draining substrates.

The same range of crops and substrates will be used in experiments on the EMWC during 2012 but instead of drip irrigation, irrigation schedules will be developed that optimise substrate moisture contents under conventional overhead or sub-surface irrigation (capillary matting). The effects of the different irrigation systems on plant growth and quality in the three substrates will be determined. The irrigation schedules developed for industry standard, peat-reduced and peat-free substrates will be demonstrated at an Irrigation Workshop to be held at the EMWC in Summer 2012 and opportunities to implement these schedules in commercial production systems will be discussed. An article summarising project aims, objectives and results to date will be submitted to HDC News at the end of March 2012.

Financial Benefits

Full cost-benefit analyses at commercial nurseries would be required to quantify precisely the potential financial benefits arising from this project. However, significant cost savings are anticipated due to lowered production costs, more efficient use of resources and reduced plant wastage. A preliminary cost benefit analysis was included in the First Annual Report for HNS 182.

Action points for growers

- Consider scheduling irrigation to all substrates using measurements of plant-and-pot weights or VSMC
- Begin to 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 reduced peat and peat-free substrates
- 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 substrates with reduced peat can be similar to industry-standard peat-based substrates but with some crops may need to be reduced 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]. Although some customers request peat-free production (*e.g*. The National Trust), the majority do not and so at the moment, there is little commercial pressure to reduce peat use. However, the UK government is committed to reducing peat use under the Biodiversity Action Programme. Following a consultation period (ending 11th March 2011), Defra has outlined plans to reduce the horticultural use of peat in England in the Natural Environment White Paper published June 2011. This includes a voluntary phase-out target of 2030 for professional growers of fruit, vegetables and plants. The proposed withdrawal of peat from the UK horticulture industry is of great concern to many HNS growers.

Recent research[4] has shown that growing HNS in even 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. To help facilitate the development of 'best' or 'better' grower practice during the transition to peat-free production, new experimentally-derived irrigation set points are needed that maintain an optimum substrate moisture content for the reduced peat and peat-free media likely to be used by HNS growers in the future.

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 initial project.

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 volumetric soil moisture content (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. Irrigation set points will be identified for each substrate and used to develop new guidelines to help growers overcome problems associated with over-watering reduced peat and peat-free alternatives.

This approach has been used very successfully to identify irrigation set points for field-grown strawberry production and water savings (and fertiliser) savings of 40% have been delivered in commercial field trials[5].

The overall aim of the project is to develop and implement improved irrigation scheduling guidelines for reduced peat, peat-free and industry standard media to help growers comply with legislation, optimise plant quality, reduce costs and gain confidence in growing HNS in peat alternatives. Despite much recent research into irrigation scheduling for the HNS sector at EMR[6,7] and elsewhere, uptake of the work by the industry has been limited and irrigation of industry standard substrates remains largely unscheduled. Consequently, industry water and fertiliser use efficiencies are often low, with associated losses of water and nutrients and lowered plant quality. It will be important to ensure that this project delivers practical solutions that fulfil the sector's requirements. Constructive advice and support from the Project Steering Group (which consists of key growers, consultants and advisors) will help to achieve this goal.

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 based on 25% bark, 75% peat supplied by Sinclair
- **Reduced peat:** substrate based on 25% wood fibre, 25% bark, 50% peat supplied by Bulrush
- **Peat free:** substrate based on peat-free materials (composted green waste and bark) supplied by Vital Earth

Specification details were obtained for each substrate; a sample of each was also sent to NRM Ltd (Bracknell, Berkshire) in February 2011 for analysis of air-filled porosity, particle size distribution, pH, density, dry matter, dry density, Ca, Cl, Mg, P, K, Na, N, EC and trace elements[8]. Plants on the EMWC were over-wintered and measurements of pot weights and VSMC were made during the winter to determine whether the more freely-draining reduced peat and peat-free substrates are less prone to waterlogging. In March 2012, samples were taken of each substrate from over-wintered pots of each crop, and values for air filled porosity were obtained.

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:

- *Sidalcea* 'William Smith'
- *Ribes sanguineum* 'Koja'
- *Escallonia rubra* 'Crimson Spire'

One hundred and fifty plug plants of *Sidalcea* were supplied by Howard Nurseries (Diss, Norfolk, UK) and fifty 9 cm liners of *Ribes* and *Escallonia* were supplied by New Place Nursery (Pulborough, West Sussex, UK). *Sidalcea* plugs were potted into 9 cm liners on 22 April.

On 28 April (*Ribes* and *Escallonia*) and on 19 May (*Sidalcea*), 9 cm liners were potted in to 3 L pots containing one of the three substrates. The bottom 20 mm of compost was gently removed to leave a root ball of about 60 mm. Plants were graded to help ensure that variability was spread evenly between different treatments and that each experimental block contained plants of equivalent grade. *Ribes* and *Escallonia* were divided into two grades – 'well-branched' and 'less well-branched'. Of 150 liners, 45 equivalent plants of *Sidalcea* were selected for potting into 3 L pots, based on the width of the crown and the number of emerging floral spikes. Controlled release fertiliser (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*. All plants were established under cover in an unheated mesh-walled tunnel and were hand-watered during establishment.

Plants were then placed on a 10 m x 5 m mypex bed (mypex laid over polythene) on the East Malling Water Centre (EMWC) (Figure GS1). Plants were spaced 8 cm apart (measured between the rims of the pots). After consulting with members of the Project Steering Group, plants were pruned as follows: *Sidalcea* plants were cut back to approximately 5 cm above soil level; *Ribes* were cut back to just above the height at which the stems had previously been pinched, i.e. between 18 cm and 26 cm, and *Escallonia* were trimmed to 22 cm. *Sidalcea* and *Escallonia* plants were again cut back, as before, on 3 September. *Sidalcea* plants were cut back at the end of the growing season (on 21 October).

Experimental design

For each crop, a complete randomised block design was used with eight experimental blocks and one non-experimental block (which was positioned centrally), each containing three plants (Figure 1). Each substrate was represented within each block; there were eight replicate plants per treatment. The blocks were flanked by guard rows: for *Escallonia* at the northern end of the bed and *Sidalcea* at the southern end of the bed there were two guard rows north and south of the blocks and one guard row east and west. *Ribes* blocks were surrounded by one guard row. Crops were separated by 1 m and situated approximately 1 m from the northern and southern edges of the bed and 0.5 m from the eastern and western sides. To allow access for routine measurements, blocks 3 and 4 and blocks 5 and 6 were separated in each crop by 0.5 m.

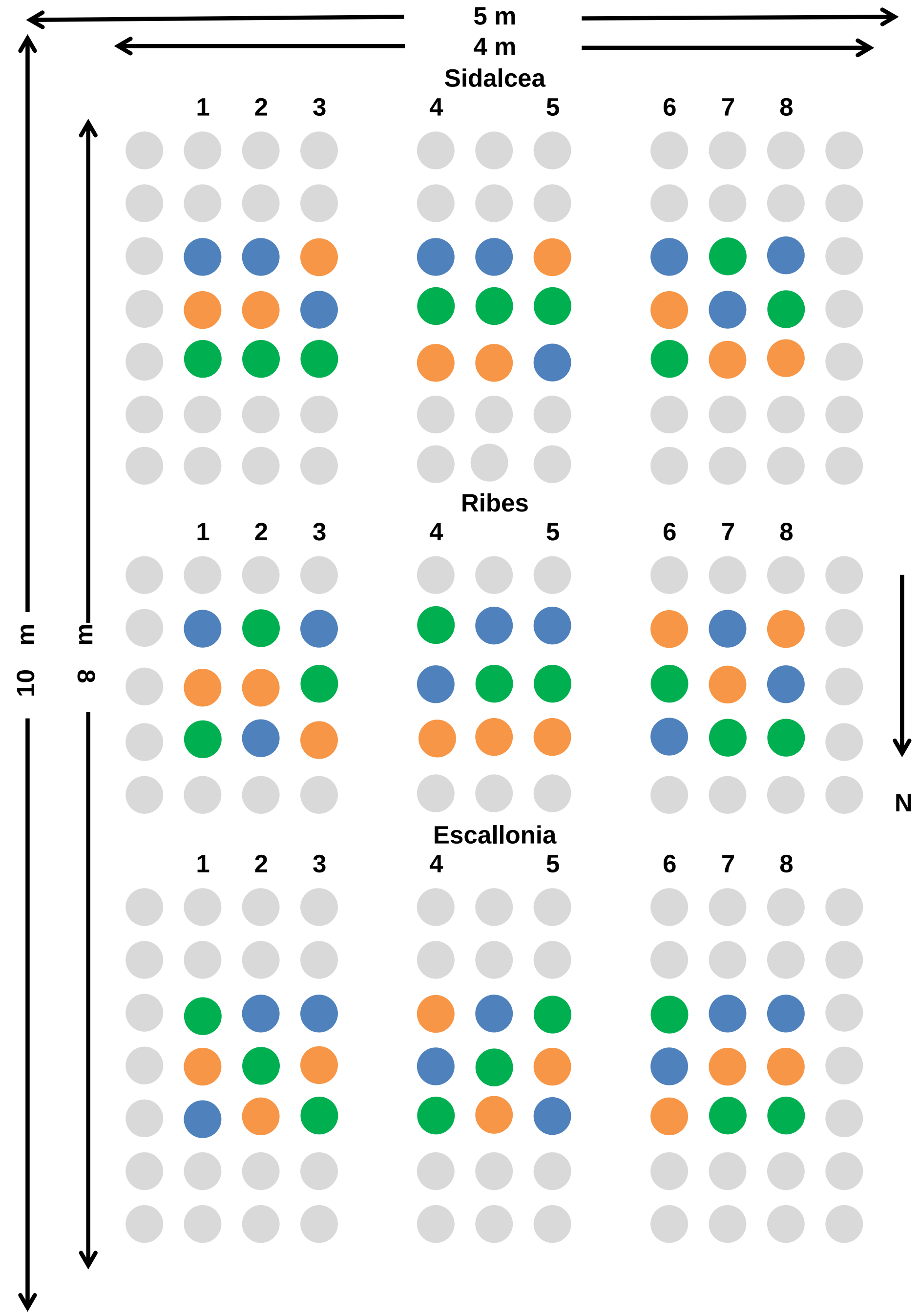

Figure 1. Experimental layout of *Sidalcea, Ribes* and *Escallonia* potted plants on EMWC. Experimental blocks are numbered. Each plant is represented by a circle: ● = guard row plant; ●, ●, ● = experimental plants in Sinclair, Bulrush and Vital Earth substrates, respectively.

Irrigation application and scheduling

Irrigation was applied automatically using nine Delta-T SM200 soil moisture probes connected to nine Delta-T GP1 data loggers (Delta-T Devices Ltd, Cambridge, UK). The soil moisture probes were inserted 6 cm below the substrate surface and placed adjacent to the irrigation stake, and were located in pots in the central, non-experimental block.

For each crop, the timing and duration of irrigation events was controlled using three 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 and irrigation was supplied to each pot *via* a dripper stake and bootlace connected to a pressure compensated 2 L h^{-1} emitter. Dripper outputs were tested prior to the experiment and during the experiment prior to conducting a comparison of irrigation frequency and duration, to ensure an accuracy of within 5% of the mean. Initially the irrigation was set to trigger automatically four times daily: at 09:00 h, 12:00 h, 15:00 h and 18:00 h. On 6 August the irrigation was set to trigger automatically every hour to help ensure that pot weights were maintained within the optimal range. To maintain VSMC and plant-and-pot weights within the optimal range identified in year 1 for each crop and substrate, the GP1 irrigation set points were frequently adjusted relative to data obtained from the experimental pots for average soil moisture contents and average plant-and-pot weights. The duration of each irrigation event was adjusted to ensure that run-through was minimised.

Irrigation was scheduled to maintain plants within the optimum ranges obtained in year 1, using values for VSMC and corresponding plant-and-pot weights obtained for 3 L pots in year two (Table GS1). In year 1, VSMC and pot weight data obtained were for 2 L pots; however at the meeting held in March 2011 with the Project Steering Group, a decision was taken to use 3 L pots in year 2. The average plant-and-pot weights at pot capacity for the eight replicate 3 L potted plants did not correspond exactly to the calculated values based on the data for seven replicate 2 L potted plants obtained in year 1; therefore for each crop and substrate linear regression analysis was carried out on a range of values collected for VSMC and 3 L plant-and-pot weights (data not shown) and the line of best fit thus obtained was used to select plant-and-pot weights for scheduling to the selected VSMC. Rates of substrate drying were low in *Ribes*, and so to enable a comparison of irrigation frequency and duration to be made between substrates, the VSMC irrigation set points were raised for Sinclair and Bulrush substrates.

A comparison of irrigation frequency was made between substrates over a period of five days between 27 September and 1 October: irrigation was triggered manually when average values for the selected lower plant-and-pot weights were obtained. Each crop and substrate was irrigated at least twice during this period (Table GS2).

Plant growth and physiology

Routine measurements of VSMC, plant-and-pot weights and plant growth and physiology were made twice weekly during the growing season (weather permitting). Transpirational water loss was determined gravimetrically between 09:00 and midday. Between 9.30 and 10.30, VSMC was measured using a Delta-T 'WET' sensor which was calibrated for each substrate. 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 down from pot shoulder and the lower sets 4 cm up from the pot base and the average pot VSMC was determined. Between 12:30 and 14:30 stomatal conductance (g_s) of fully expanded leaves were measured using a leaf porometer (Decagon Devices). To assess petiole and leaf extension rates, weekly measurements were made of *Sidalcea* leaf petioles and *Ribes* and *Escallonia* leaf lengths. Whole plant growth was also assessed by measuring plant height and spread at the beginning of the experiment and at intervals during the growing season: Sidalcea plants were measured on 21 July, 24 August, 5 October and 20 October; *Ribes* measurements were made on 21 July, 28 August and 5 October; and measurements of *Escallonia* plants were made on 21 July, 24 August and 14 October. Values for *Sidalcea* plant dry weight were obtained on 24 October.

Assessment of plant quality was made by industry experts, at simulated dates of sale. Visual inspections of root and canopy health were carried out in the following spring to determine whether plant health and vigour were improved in the more freely-draining substrates.

Statistical analyses

Statistical analyses were carried out using GenStat 10th 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. For cases where more than 10% of values were missing, analysis of an unbalanced design using GenStat regression was carried out. Simple linear regression was performed to assess the relationship between variables and the percentage variance accounted for was calculated.

Results

Industry standard, reduced peat and peat-free substrates

Average plant-and-pot weight during the winter (Table 1) differed significantly between substrates only on 15 November 2011 (when average pot weight was higher for *Sidalcea* plants growing in Vital Earth substrate compared to Sinclair and Bulrush substrates).

Values for average VSMC obtained during the winter (Table 1) were significantly lower for Vital Earth substrate compared to Sinclair and Bulrush substrates for Sidalcea in February, significantly lower for Vital Earth substrate compared to Sinclair substrate for Ribes in November and January, and significantly lower for Vital Earth substrate compared to both Sinclair and Bulrush substrates in February. For Escallonia, in January the VSMC values for Sinclair and Bulrush substrates were significantly lower compared to Vital Earth substrate. Values for air filled porosity of each substrate from over-wintered posts of each crop were obtained in March 2012 and will be presented in the Final Report.

Table 1. Average values for VSMC and corresponding plant-and-pot weights in November 2011, January 2012 and February 2012 for *Sidalcea*, *Ribes* and *Escallonia* plants grown in each of the three substrates in 3 L pots. Data are means of eight replicate plants (A, C) and seven replicate plants (B) with associated standard errors of the mean values.

A) *Sidalcea*

Substrate	**Plant-and-pot weights and VSMCs for each substrate**					
	Pot weight (g)			**VSMC ($m^3 m^{-3}$)**		
	15/11/11	**11/01/12**	**17/02/12**	**15/11/11**	**11/01/12**	**17/02/12**
Sinclair	1837 ± 30	1792 ± 28	2012 ± 28	0.45 ± 0.01	0.41 ± 0.01	0.50 ± 0.01
Bulrush	1865 ± 24	1828 ± 25	2021 ± 29	0.47 ± 0.01	0.45 ± 0.02	0.53 ± 0.02
Vital Earth	1984 ± 33	1872 ± 27	1998 ± 30	0.43 ± 0.02	0.35 ± 0.02	0.42 ± 0.02

B) *Ribes*

Substrate	Plant-and-pot weights and VSMCs for each substrate					
	Pot weight (g)			VSMC (m^3 m^{-3})		
	15/11/11	11/01/12	17/02/12	15/11/11	11/01/12	17/02/12
Sinclair	1779 ± 36	1733 ± 35	1908 ± 31	0.44 ± 0.01	0.41 ± 0.01	0.48 ± 0.01
Bulrush	1742 ± 31	1727 ± 25	1909 ± 19	0.40 ± 0.01	0.39 ± 0.01	0.47 ± 0.01
Vital Earth	1830 ± 78	1799 ± 30	1882 ± 34	0.37 ± 0.01	0.35 ± 0.01	0.41 ± 0.01

C) *Escallonia*

Substrate	Plant-and-pot weights and VSMCs for each substrate					
	Pot weight (g)			VSMC (m^3 m^{-3})		
	15/11/11	11/01/12	17/02/12	15/11/11	11/01/12	17/02/12
Sinclair	1976 ± 34	1604 ± 37	1939 ± 33	0.48 ± 0.02	0.32 ± 0.01	0.48 ± 0.01
Bulrush	1992 ± 28	1596 ± 31	1914 ± 45	0.48 ± 0.01	0.33 ± 0.01	0.48 ± 0.02
Vital Earth	1903 ± 42	1634 ± 38	1831 ± 42	0.49 ± 0.03	0.38 ± 0.03	0.49 ± 0.03

Irrigation application and scheduling

For each crop and substrate, the volume of irrigation which could be applied at the lower set point before more than 5% run-through occurred was established, and irrigation frequency and total volume applied to maintain optimal pot weights over a defined number of degree hours was determined (Table GS2).

For industry standard substrate (Sinclair) and peat-reduced substrate (Bulrush), run-through occurred at similar irrigation volumes, with the exception of *Ribes* growing in Bulrush substrate where this volume was approximately 50% less. For plants growing in peat-free (Vital Earth) substrate, the run-through occurred at reduced irrigation volumes compared to industry standard substrate; volumes applied were less by approximately 30% for *Sidalcea* plants and 50% for *Ribes* and *Escallonia* plants.

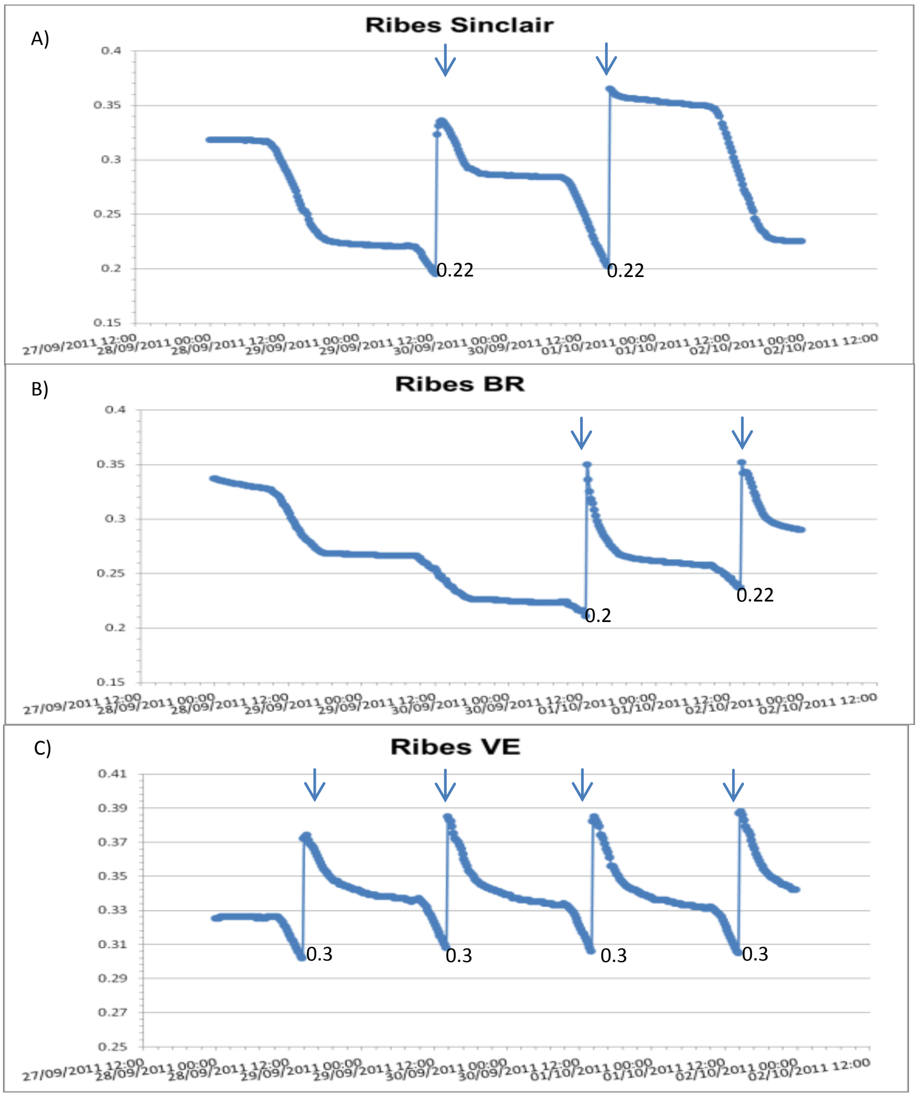

Figure 2. GP1 logger data showing frequency of irrigation events during the period 27 September to 2 October 2011, for *Ribes* plants growing in A) Sinclair, B) Bulrush and C) Vital Earth substrates. Arrows indicate irrigation events. Values for lower irrigation set points are shown for each substrate and irrigation event.

Plant growth and physiology

Plant-and-pot weights were maintained within the optimal range determined for each crop and substrate (Figure 3). In year 1, stomatal conductance (g_s) was shown to be a sensitive indicator of substrate drying and therefore was used in the second year to monitor plant responses to the irrigation schedules. Values for g_s in each of the crops and substrates varied with changes in evaporative demand (Figure 4) but the relatively high mean values (≥ 400 mmol m^{-2} s^{-1}) indicated that plants were transpiring freely and that soil water availability was optimal. Significant differences in values between crops were not detected.

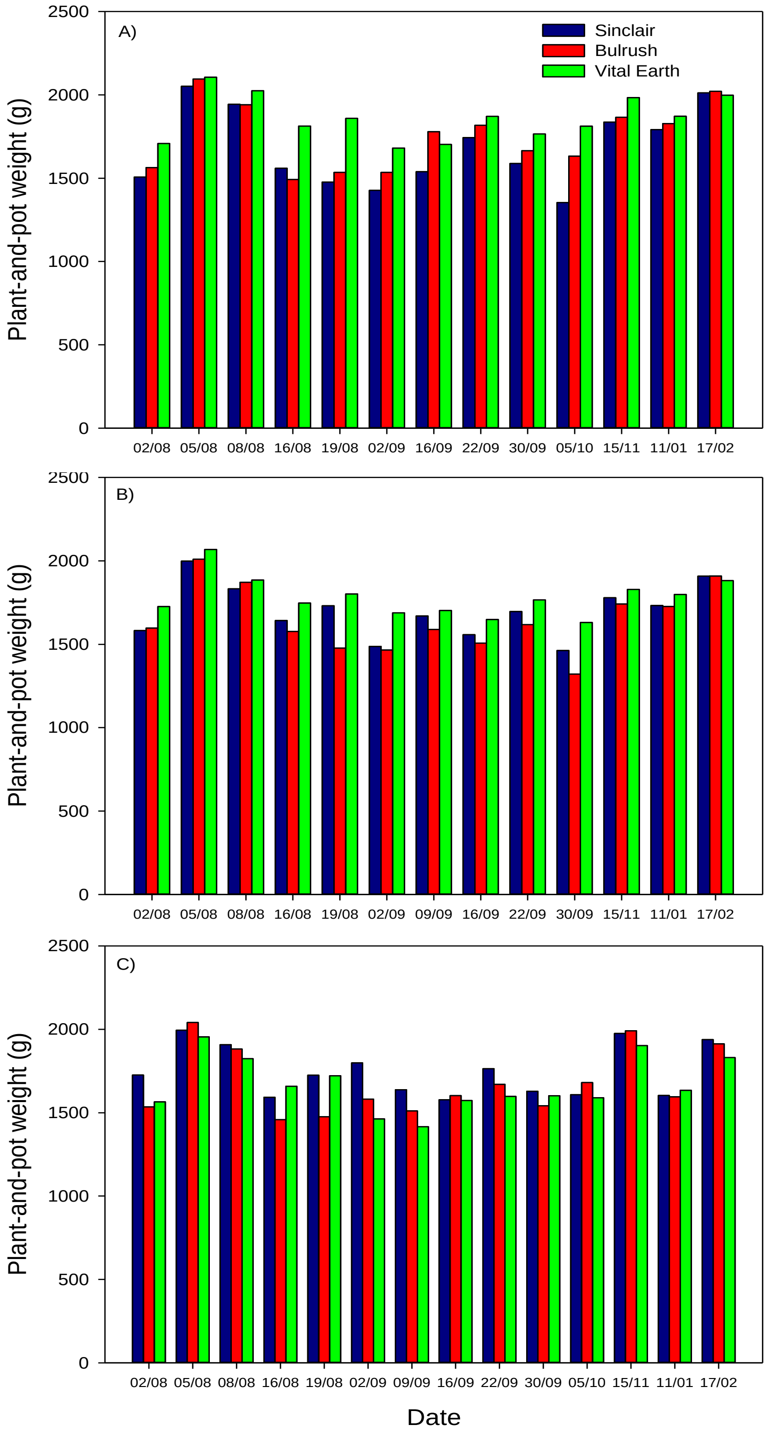

Figure 3. Plant-and-pot weight data for A) *Sidalcea,* B) *Ribes* and C) *Escallonia* plants growing in Sinclair, Bulrush and Vital Earth substrates from August 2011 to February 2012.

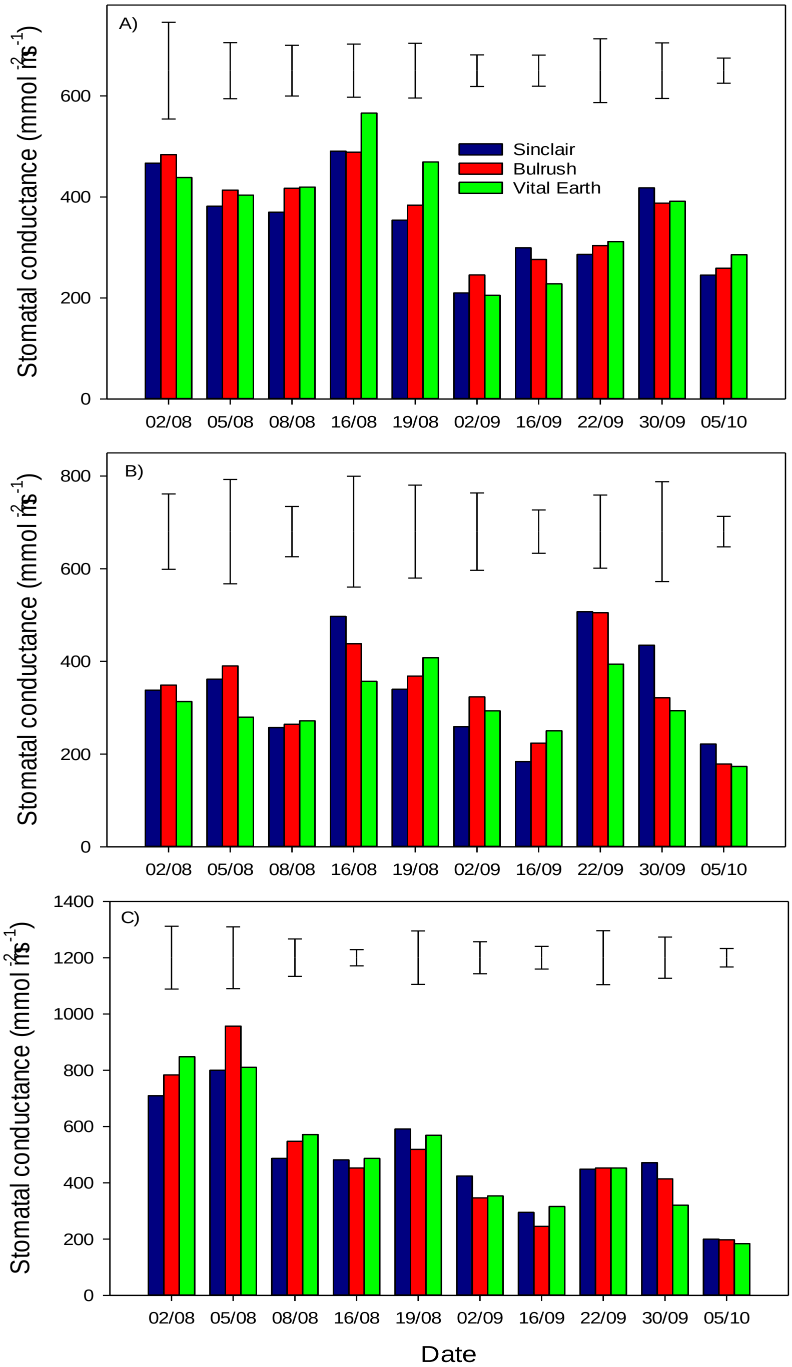

Figure 4. Stomatal conductance of A) *Sidalcea*, B) *Ribes* and C) *Escallonia* potted plants growing in Sinclair, Bulrush and Vital Earth substrates during August and September 2011. For *Sidalcea* results for all dates are means of eight replicate plants. For *Escallonia* results for all dates except 5 October are for eight replicate plants; on 5 October results are for three replicate plants. For *Ribes* results are for means of a variable number of replicates, as follows for the following substrates and dates (number of replicate plants in brackets): Sinclair 2 August to 2 September (7), 16, 22, 30 September and 5 October (5); Vital Earth 16 September to 5 October (7); Bulrush 16 September to 30 September (7), 5 October (6). For each crop and date, there were no significant differences between substrates in values obtained. LSD values are for $P \leq 0.05$, with 14 degrees of freedom, except for the following crops and dates (d.f. in brackets): *Escallonia* 5 October (4); *Ribes* 2 August to 2 September (13) degrees of freedom; and for all *Ribes* for 16 and 22 September (9), 30 September (10), 5 October (6).

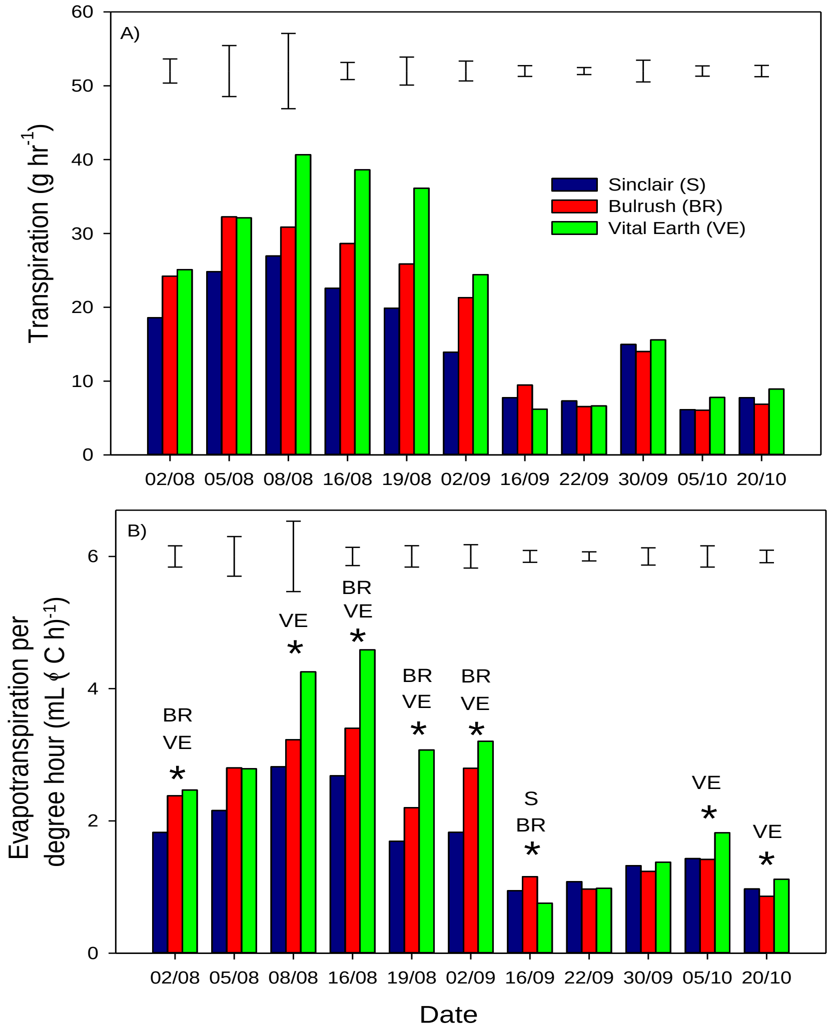

Figure 5. A) Whole-plant transpiration rate and B) evapotranspiration per degree h of potted *Sidalcea* plants grown in Sinclair, Bulrush and Vital Earth substrates. Asterisks indicate dates, which are the same for both A) and B), when physiological responses were first detected for all three substrates. Results are means of eight replicate plants; LSD values are for $P \leq 0.05$ with 13 degrees of freedom.

Measures of transpiration (*E*) integrate the stomatal responses of all leaves, therefore in all crops they too were influenced by changes in evaporative demand (Figures 5-7). Rates were relatively slow during overcast weather and increased during sunny weather. Differences in evaporative demand caused by variations in ambient conditions can be accounted for, at least in part, by calculating rates of evapotranspiration (*Etp*) per degree h. Although these rates were more consistent between different dates, where significant differences occurred they were detected on the same dates as for *E*.

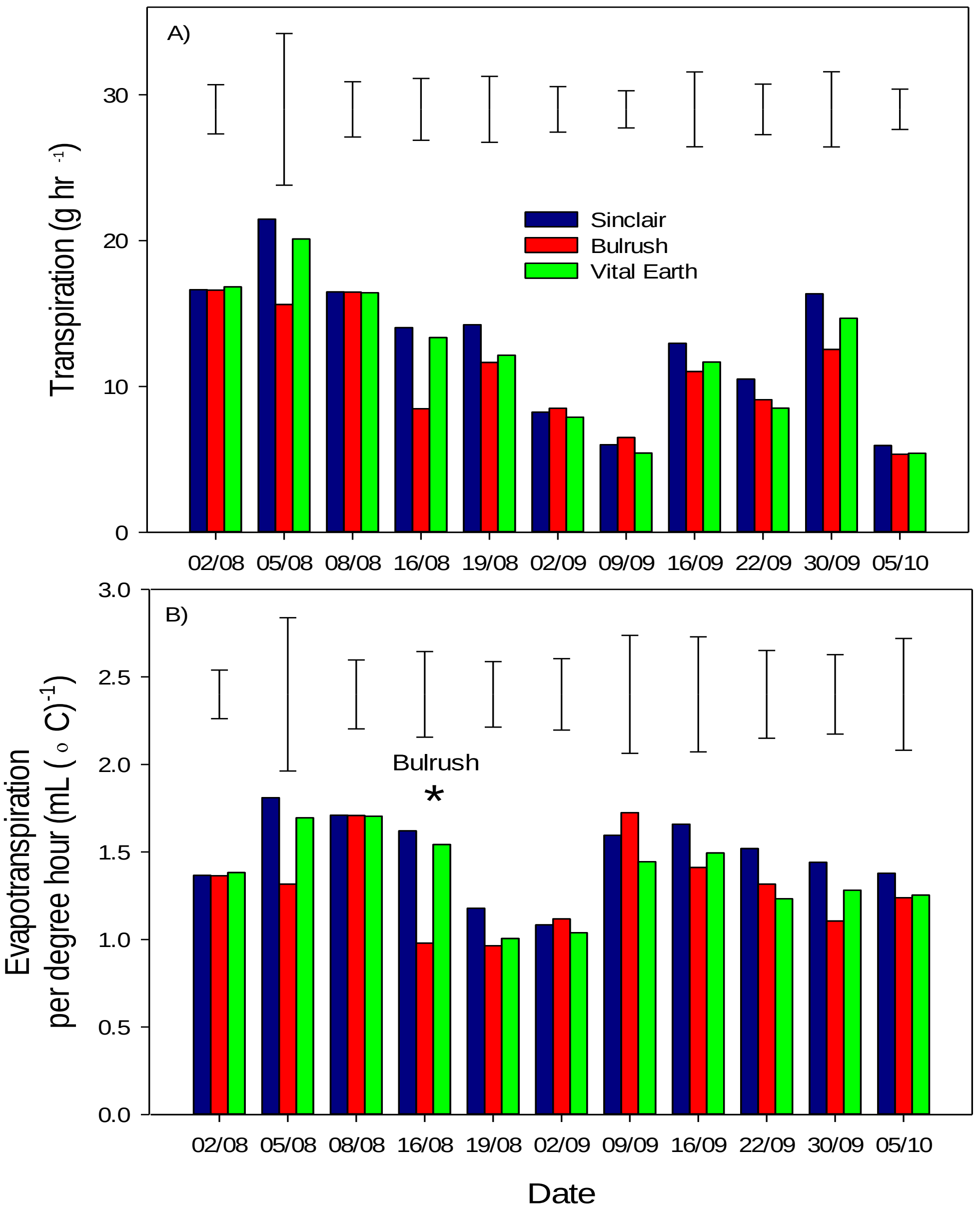

Figure 6. A) Whole-plant transpiration rate and B) evapotranspiration per degree h of potted *Ribes* plants grown in Sinclair, Bulrush and Vital Earth substrates. Results are means of eight replicate plants except for the following substrates and dates (number of replicate plants in brackets): Sinclair 2, 5 and 16 August to 9 September (7), 8 August (6), 16 September to 5 October (5); Bulrush and Vital Earth 16 September to 5 October (7). Asterisk indicates the date for both A) and B) when physiological responses were detected between substrates. LSD values are for $P\leq0.05$ with 13 degrees of freedom for 2, 5 and 16 August to 9 September; 11 degrees of freedom for 8 August; and 9 degrees of freedom for 16 September to 5 October.

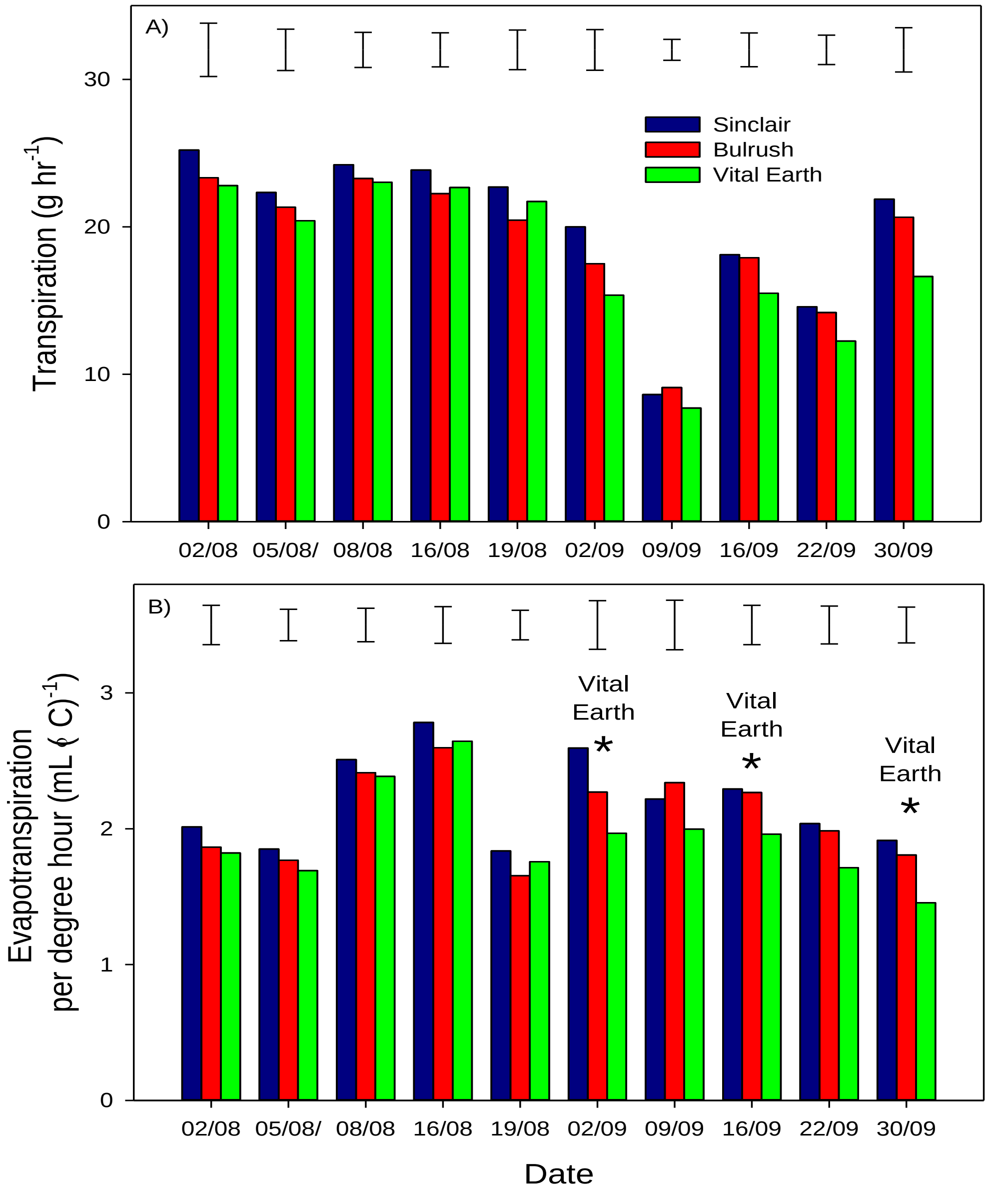

Figure 7. A) Whole-plant transpiration rate and B) evapotranspiration per degree h of potted *Escallonia* plants grown in Sinclair, Bulrush and Vital Earth substrates. Results are means of eight replicate plants except for Sinclair on 5 August and 22 September, Bulrush on 5 August and Vital Earth on 8, 19 August and 22 September when results are for seven replicate plants. Asterisks indicate dates, which are the same for both A) and B), when physiological responses were first detected for all three substrates. LSD values are for $P \leq 0.05$ with 14 degrees of freedom, except 13 degrees of freedom for 8 and 19 August, and 12 degrees freedom for 5 August and 22 September.

In year 1, petiole (*Sidalcea*) and leaf (*Ribes* and *Escallonia*) extension growth were shown to respond to substrate drying, first detected one to six days after other physiological responses (i.e. *E* and g_s); therefore petiole or leaf growth was also measured during the growing season in the second year. In all crops, there were no significant differences in the average rates of petiole or leaf growth between plants growing in different substrates (Figure 8).

In year 1, plant growth decreased in response to substrate drying. In response to irrigation scheduling imposed in year 2, there were no significant differences in average plant heights, plant spread or plant growth rates of *Ribes* and *Escallonia* plants growing in Sinclair, Bulrush or Vital Earth substrates (Figures 9 and 10). Spread of *Sidalcea* plants was greater for plants growing in Vital Earth substrate than for Bulrush on 5 October and greater than Bulrush and Sinclair on 21 October, but there were no significant differences for mean values obtained for height or height growth rate (Figure 11). For *Sidalcea* plants harvested at the end of October the mean value obtained for plant (leaf and stem) dry weight was significantly higher for plants grown in Vital Earth substrate. There was a significant correlation between plant dry weight and *Etp* (Figure 12).

An assessment of plant quality was made by members of the Project Steering Group, for *Sidalcea* during the growing season in 2011, and for *Sidalcea, Ribes* and *Escallonia* in spring of 2012. *Sidalcea* plants growing in industry standard (Sinclair), reduced peat (Bulrush) and peat-free (Vital Earth) substrates were graded as first grade (suitable for garden centre sales), second grade (suitable for the landscape use) and third grade (not saleable on the date of assessment) on 21 September and at simulated date of sale on 6 October. On 21 September, five, three and five of eight replicate plants, and on 6 October seven, five and six replicate plants growing in Sinclair, Bulrush and Vital Earth substrates respectively were considered saleable. There was no significant difference on either date in average grade-out between plants growing in peat-free, peat-reduced and industry standard substrates (data not shown). Results of plant quality assessments (including root and canopy health) made during March and April 2012 will be presented in the project Final Report.

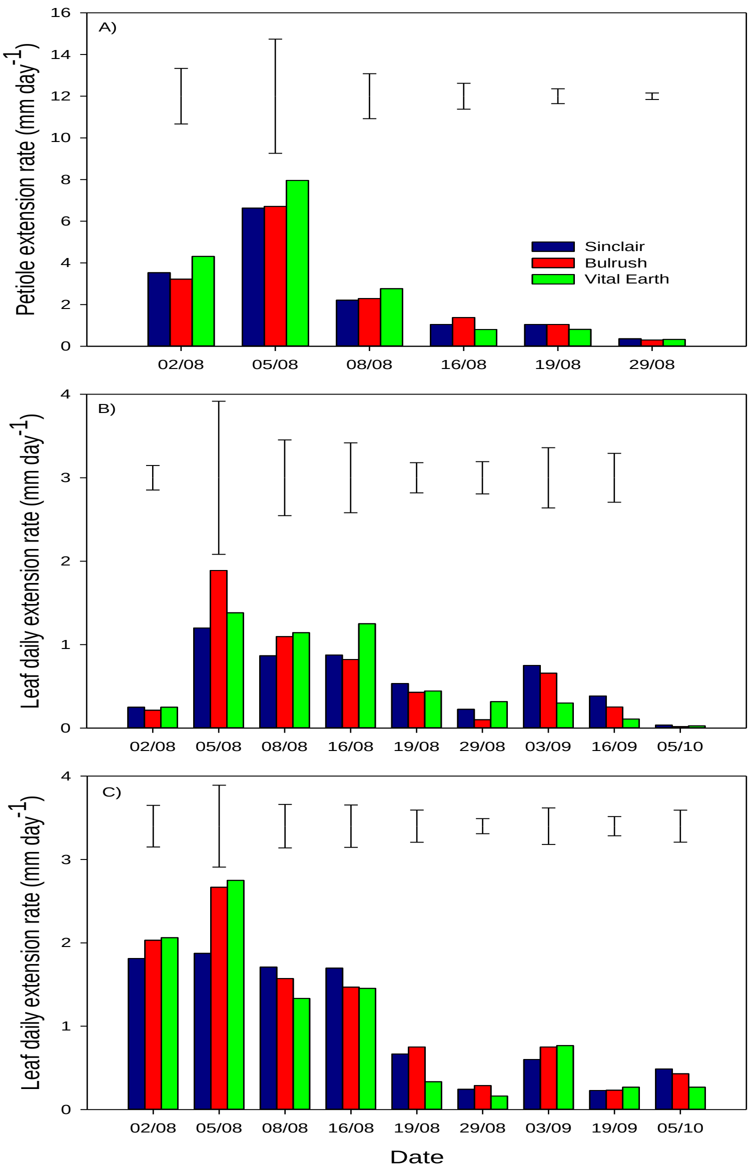

Figure 8. Petiole or leaf extension rate of A) *Sidalcea,* B) *Ribes* and C) *Escallonia* potted plants grown in Sinclair, Bulrush and Vital Earth substrates during August and September 2011. Results are means of eight replicate plants except for the following crops, substrates and dates (number of replicate plants in brackets): *Sidalcea* Sinclair 19, 29 August (7); *Sidalcea* Vital Earth 8, 16, 19, 29 August (7); *Sidalcea* Bulrush 19 August (7), 29 August (6); *Ribes* Sinclair 2, 8, 16, 19 August (7), 5 August (6), 29 August (4), 3 September (5), 16 September (3), 5 October (3). *Escallonia* Sinclair 16, 18, 29 August (7), 3, 19 September (6), 5 October (5); *Escallonia* Bulrush 8 August (7), 19 September (7), *Escallonia* Vital Earth 8 August (7), 3 September (6), 19 September (7), 5 October (7). For each crop and date, there were no significant differences between substrates in values obtained. LSD values are for $P \leq 0.05$, with variable degrees of freedom as follows for the following crops and dates (degrees of freedom in brackets): *Sidalcea* 2, 5 August (14), 8 August (12), 16 August (13), 19 August (11), 29 August (10); *Ribes* 2, 8 August (13), 16, 19 August (12), 5, 8 August (10), 29 August (7), 3 September (7), 16 September (5), 5 October (2); *Escallonia* 2, 5 August (14), 16, 19, 29 August (13), 8 August (12), 3, 19 September and 5 October (10).

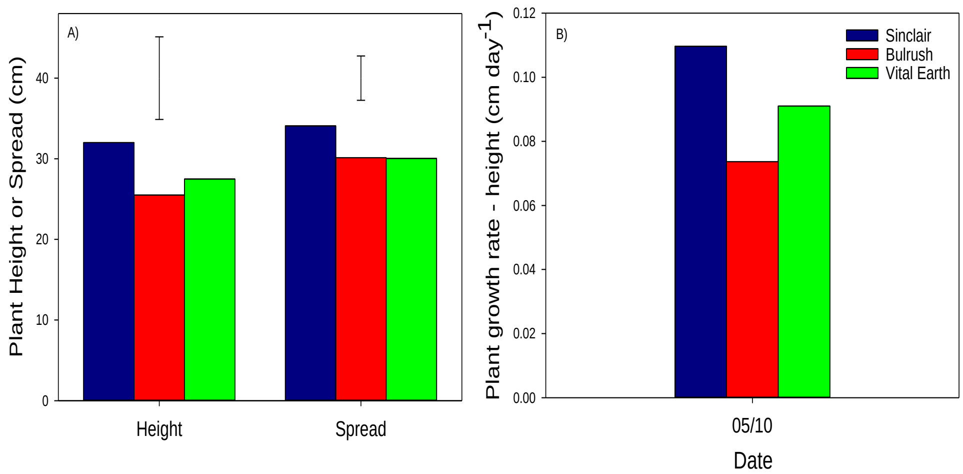

Figure 9. A) Plant height and spread on 5 October, and B) plant height growth rate between 21 July and 5 October 2011, of *Ribes* potted plants grown in Sinclair, Bulrush and Vital Earth substrates. Results are means of three replicate plants for Sinclair substrate, and seven replicate plants for Bulrush and Vital Earth substrates. There were no significant differences between substrates in values obtained. LSD values are for $P \leq 0.05$, with seven degrees of freedom for plant height and spread and four degrees of freedom for plant growth rate.

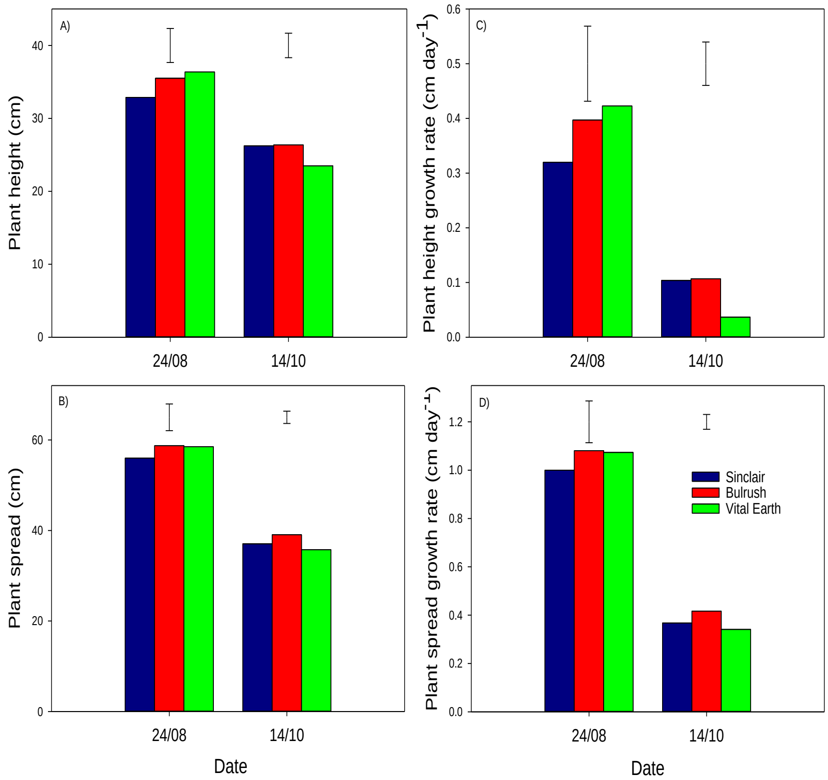

Figure 10. A) plant height and B) plant spread on 24 August and 14 October, C) plant height growth rate and D) plant spread growth rate between 21 July and 24 August and 3 September and 14 October 2011, of *Escallonia* potted plants grown in Sinclair, Bulrush and Vital Earth substrates. Results are means of eight replicate plants. There were no significant differences between substrates in values obtained. LSD values are for $P \leq 0.05$, with fourteen degrees of freedom.

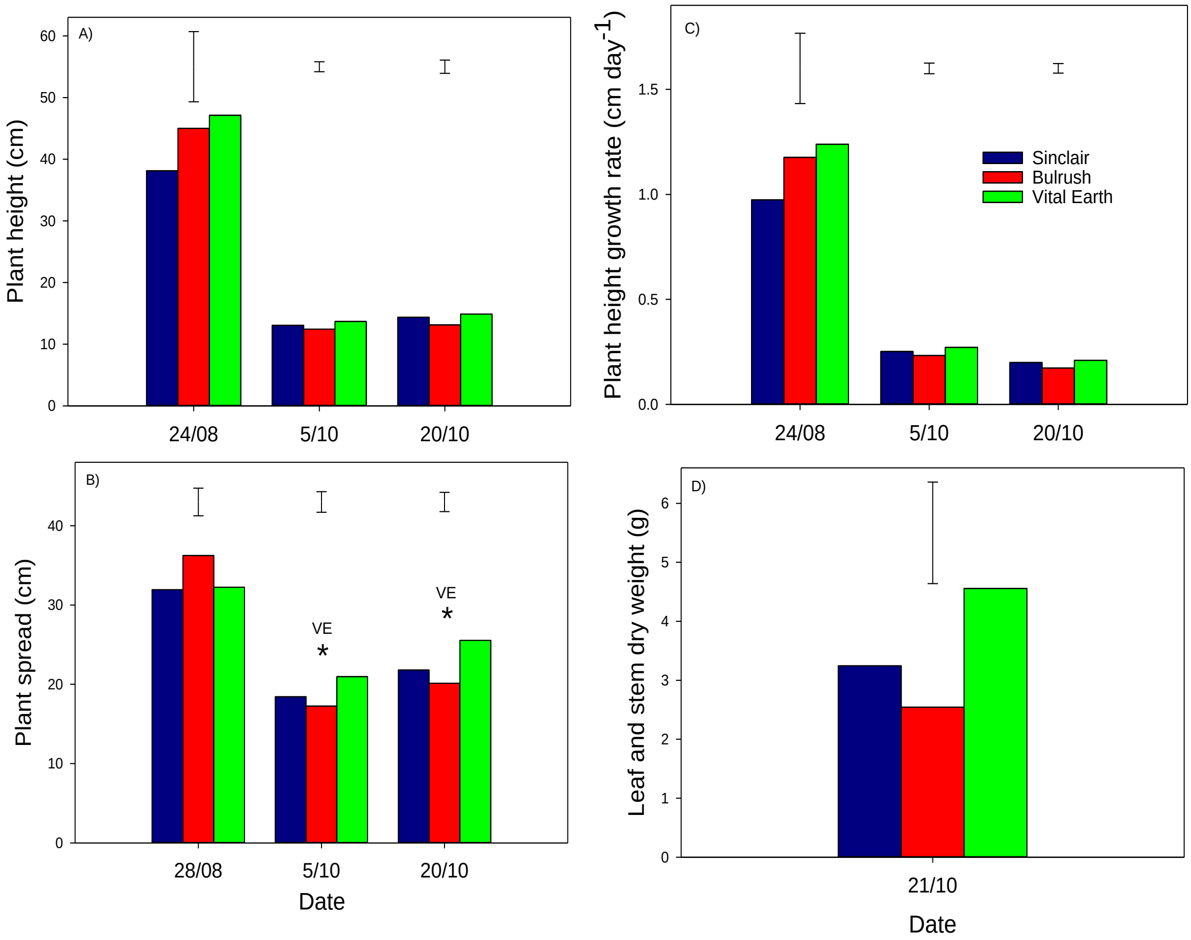

Figure 11. A) plant height and B) plant spread on 24 August, 5 October and 20 October, C) plant height growth rate between 21 July and 24 August, 3 September and 5 October and D) plant leaf and stem dry weight 21 October 2011, of *Sidalcea* potted plants grown in Sinclair, Bulrush and Vital Earth substrates. Results are means of eight replicate plants (A-C) or seven replicate plants (D). Asterisks indicate when physiological responses were detected between substrates. LSD values are for $P \leq 0.05$, with fourteen degrees of freedom (A-C) or 12 degrees of freedom (D).

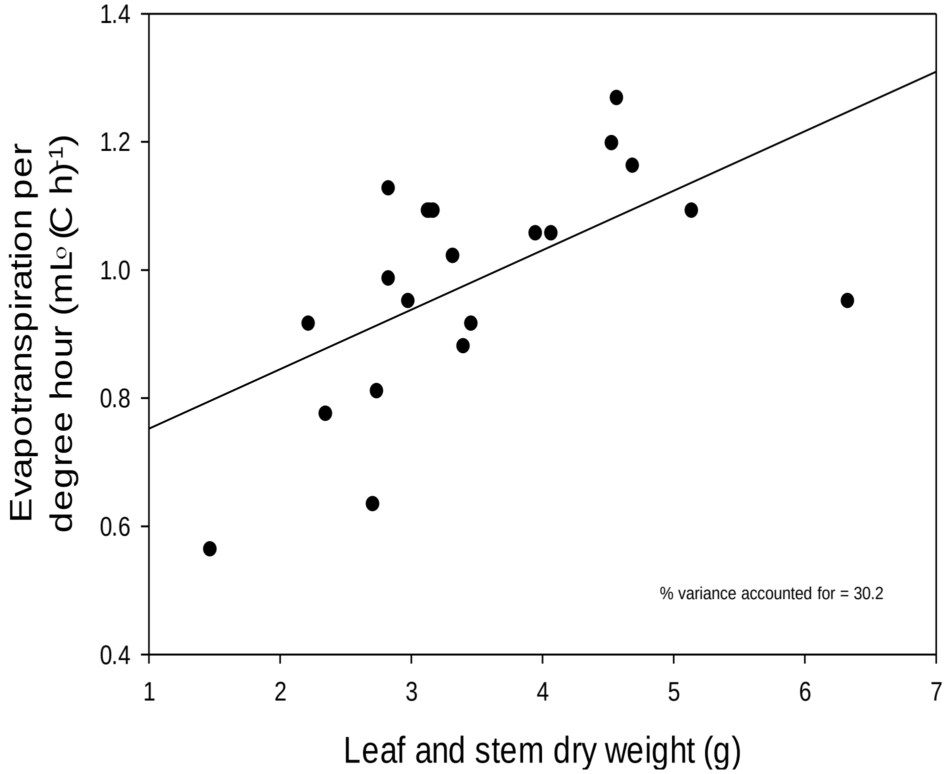

Figure 12. Comparative analysis of leaf and stem dry weight and evapotranspiration, of potted *Sidalcea* plants growing in Sinclair, Bulrush and Vital Earth substrates, 20 October 2011. Regression analyses included data from 21 plants, thus the residual degress of freedom for the linear regression with one explanatory variable are 19 degrees of freedom. *P*=0.006.

Discussion

The main aim of the work in the second project year was to schedule 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. This enabled a comparison to be made of irrigation volumes and frequencies between substrates, and also an evaluation of whether plant growth and quality in peat-free and reduced peat substrates were similar to those in industry standard substrate, when irrigation scheduling is optimised.

One aim of this project is to develop a practical irrigation scheduling tool for use on commercial nurseries. Therefore, irrigation was scheduled to each species in each of the substrates during the 2011 growing season using Delta-T SM200 soil moisture probes connected to a GP1 data logger. This system was used with great success at Hillier Nurseries Ltd in HortLINK project 97b; water savings of 80% were achieved over the season, compared to plants where irrigation frequency and duration were decided by Hillier staff. Straightforward plant-and-pot weighing could also be used to schedule irrigation effectively on smaller to medium size nurseries.

In each crop, the water-holding capacity of the substrate was less than the volume of water needed to return pots to the upper set point once the lower irrigation set point had been reached. Therefore, irrigation was pulsed to ensure that run-through was minimised during re-wetting of the substrates. Compared to industry standard substrate, irrigation volumes applied were 30-50% less for plants growing in peat-free substrate, reflecting its relatively poor water-holding capacity. For industry standard substrate, the irrigation volume at which run-through occurred was very similar for each of the three species. However, for peat-reduced and peat-free substrates, the irrigation volume at which run-through occurred varied between crops; this may have been due to the variability in substrate composition or may reflect differences in rates of water uptake by roots following irrigation events. The lower irrigation volumes necessitated more frequent irrigation events in the peat-free substrate compared to the industry standard and peat-reduced substrates.

Significant differences in transpiration were detected in each crop on some dates during the growing season, but significant differences in stomatal conductance and petiole or leaf extension rate were not observed. As both stomatal conductance and leaf extension were shown in the first year of the project to be sensitive indicators of substrate drying, it is therefore likely that the observed differences in transpiration rates of plants growing in different substrates was due to variation in plant canopy leaf area. A strong correlation was observed between leaf (and stem) dry weight and transpiration of *Sidalcea* plants, however assessment of leaf area by measurement of dry weight in *Ribes* or *Escallonia* was not possible as this would have required destructive harvesting. As variation in transpiration rates in these crops could not be explained by differences in stomatal conductance or leaf or plant growth rate, it is likely that differences in transpiration rate were due to variation in plant canopy leaf area and not physiological stress imposed by substrate drying.

Average plant grade-out at simulated dates of sale was similar for *Sidalcea* plants growing in peat-free, reduced peat substrates, and industry standard substrates (Figure GS3). This suggests that the upper and lower irrigation set points derived for the three substrates would be suitable for the commercial production of *Sidalcea*. The quality of *Ribes* and *Escallonia* in each of the three substrates will be determined in Spring 2012.

For the *Sidalcea* and *Ribes* crops, significantly lower average values of VSMC were obtained in January and February for Vital Earth substrate compared to the Sinclair and Bulrush substrates. This indicates that, as expected, peat-free substrates are less prone to waterlogging. Due to dry winter conditions, values for VSMC were generally low in January compared to November and February; therefore the higher average VSMC value obtained in January for Vital Earth compost compared to the other two substrates in the *Escallonia* crop probably reflects differences in plant canopy leaf area resulting in a lower average plant transpiration rate of plants growing in Vital Earth substrate.

Conclusions

- Water holding capacity of substrates was 30-50% less in peat-free substrate than industry standard substrate and in peat-reduced and peat-free substrates varied with crop
- Irrigation frequency was higher for crops growing in peat-free substrate compared to crops growing in industry standard and peat-reduced 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 findings of year 2 will be tested for wider commercial relevance in year 3, when a narrower range of substrates will be selected, all produced by the same company to ensure uniformity, using irrigation systems commonly used by commercial growers
- Scientifically-derived guidelines will be used to develop practical ways to help growers to optimise irrigation scheduling and plant quality when using reduced peat, peat-free or industry standard substrates

Knowledge exchange and Technology Transfer

- A meeting with the Project Steering Group was held on 7th March 2012 to discuss approaches and finalise experimental plans, discuss results, view on-going trials and plan knowledge exchange and technology transfer events
- The Project Steering Group were consulted during the experiment, to ensure industry relevance
- Industry experts performed assessments of crop quality

Visits to Grower sites

Managing production using peat alternatives was a key topic covered in discussions with the following growers in 2010 and 2011: Jim Willis (Binsted Nursery); Karl O'Neill and Geoff Caesar (Bransford Webbs); Alastair Hazell (Darby Nursery Stock Ltd); Fizz Newington (Dingley Dell Nurseries); Nick Dunn (Frank P Matthews Ltd); Paul Dyer (Hedgehog Plants); Paul Howling (Howard Nurseries); John Hall (John Hall Plants); John Richards (John Richards Nurseries); Malcolm Dick (John Woods Nurseries); Charles Carr and Ian Ashton (Lowaters Nursery); Robert Small (North Hill Nurseries); Toby Marchant (Orchard Dene Nurseries); Lee Woodcock (Palmstead Nurseries); Peter Blakey (Plants Ltd); Bill Godfrey (W Godfrey & Sons Ltd); David Hide and Tim Lawrence-Owen (Walberton Nursery); Paul Wharton and Robert Wharton (Whartons Nurseries).

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