Project title:	Improving water and fertiliser use efficiencies and fruit quality in commercial substrate strawberry production
Project number:	SF 136
Project leader:	Dr Mark A. Else
Report:	Final Report, March 2013
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Location of project:	East Malling Research
Industry Representatives:	Mr Stephen McGuffie Mr Andrew Chesson
Date project commenced:	1 April 2012
Date project completed (or expected completion date):	31 March 2013

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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.

Michael J. Davies
Project Manager
East Malling Research

Signature .... Date ....

Report authorised by:

Dr Mark A. Else
Programme Leader
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East Malling Research

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GROWER SUMMARY

Headlines

- A new 'closed loop' irrigation system for substrate strawberry production was developed and evaluated on two commercial grower sites
- Irrigation was triggered irrigation automatically, so that coir volumetric moisture contents were maintained between upper and lower set points, irrespective of changing evaporative demand
- The automated irrigation system was used to control the volume of run-off at different stages of crop development and/or to eliminate run-off completely
- Water and fertiliser savings of 17% and 11% were achieved in experiments at Manor Farm and New Farm, respectively. Class 1 yields were maintained and berry quality was improved
- Using five 1.2 L h^{-1} emitters per 1-m-substrate bag improves the distribution of water and provides more flexibility than using a 6 L h^{-1} emitter with four lateral dripper spikes

Background and expected deliverables

More efficient use of inputs including labour, water and fertilisers is vital to the future success of the UK soft fruit industry. Recent droughts, particularly affecting the south east and east regions (Figure 1) have highlighted the need for growers to use water (and fertilisers) more efficiently. Trickle irrigation has been exempt from legislation until now but it is envisaged that drip irrigators will require an abstraction licence in future and growers must be able to demonstrate an efficient use of water to comply with legislation. There is also concern about the effects of intensive table-top soft fruit production on groundwater quality in the south east and the Environment Agency commissioned ADAS to promote 'best practice' in a series of grower workshops in 2012.

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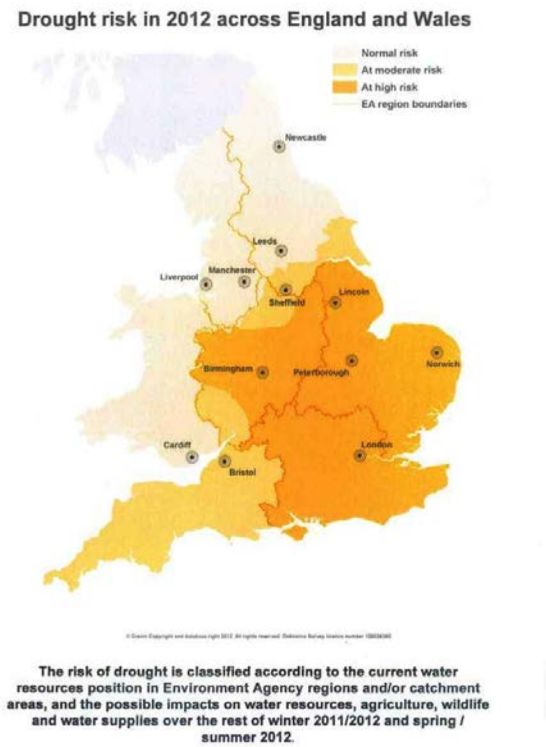

Figure 1. Assessment of drought risk across England and Wales for 2012. Source: the EA.

However, there are few practical guidelines for growers on how best to schedule irrigation, and matching demand with supply can be difficult in changeable summer weather. Many substrate strawberry growers are advised to irrigate to achieve 10-20% run-off, in part to avoid dry spots within the substrate but mainly to prevent the accumulation of potentially damaging ‘salts’. This approach can lead to excessive vegetative growth, increased disease, and fruit with a reduced shelf-life and associated increases in waste fruit. Berry eating quality can also be reduced because key flavour compounds are diluted by the high water content.

If soft fruit growers are to maintain or increase yields against a backdrop of increasing summer temperatures, dwindling water supplies, and governmental demands for greater environmental protection, new production methods that improve water and nutrient use efficiency and utilise ‘best practice’ are needed.

Expected deliverables are:

- Irrigation guidelines to optimise water (and fertiliser) use efficiency in substrate strawberry production;
- Improved economic and environmental sustainability of substrate strawberry production;
- Demonstrable compliance with legislation (Water Framework Directive, The Water

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Act, The Nitrate Directive);

- The development of a 'closed loop' irrigation scheduling tool that triggers irrigation automatically according to plant water use so that water demand can be matched with supply.

Summary of the project and main conclusions

Minimising the daily volume of run-off during changeable summer weather can be challenging, especially when substrate EC levels also need to be managed carefully. In previous HDC-funded work (SF 107) carried out by Dr Else's team at East Malling Research (EMR), new techniques to save water and fertiliser use in substrate-grown crops of 'Elsanta' and 'Sonata' were developed. An irrigation scheduling regime that matched water supply to demand, thereby eliminating run-off, was designed using irrigation set points based on plant responses to decreasing substrate moisture contents. In scientific experiments, water and fertiliser savings of 15% for 'Elsanta' and 45% for 'Sonata' were achieved without sacrificing any Class 1 yield, compared to a commercial regime where run-off averaged 20% over the season. Aspects of fruit quality were also improved, compared to 'commercial controls'. This irrigation/fertigation strategy needed to be tested in commercial grower experiments to help ensure relevance to the industry and to take account of differences in water quality and background EC.

In HDC SF 136, EMR carried out experiments at Andrew Chesson's farm (Manor Farm, S.H. Chesson Partnership, Oldbury, Ightham, Kent) and at Stephen McGuffie's farm (New Farm Produce Ltd, Elmhurst, Lichfield, Staffordshire). The aim of the project was to develop an irrigation scheduling tool that triggers irrigation automatically, according to plant water use so that water demand is matched with supply. By adjusting the irrigation set points, it should be possible to reduce or eliminate run-off of water and fertilisers, without reducing Class 1 yields or quality.

Experimental design

At each of our grower sites, 'Elsanta' wase planted into coir bags in late April and early May at Manor Farm and New Farm Produce. There were ten and eight plants per 1-m-long bag at Manor Farm and New Farm, respectively. All plants established well (Figure 2). The experiments compared the growers' usual methods of irrigation scheduling (Commercial Control - CC) with a Grower Test Regime (GTR) developed at EMR in Defra- and HDC-funded research. Each experiment was set up in a fully replicated randomised block design to ensure statistical rigour; to achieve this, two separate header pipes were installed at each site so that irrigation to the CC and GTR treatments could be applied independently.

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Figure 2. All ‘Elsanta’ plants established wall at Manor Farm, Oldbury, Kent. Photo taken on 25 May 2012

During establishment, all plants were irrigated and fertigated according to usual grower practice. The experiment at SH Chesson Partnership was covered in the last week of May and so the frequent rainfall during May helped to reduce ‘blue water’ inputs (fresh water from surface or ground water sources). The experiment at New Farm Produce was covered from planting and so irrigation was needed from the outset to aid establishment.

Probes that monitor hourly changes in coir volumetric moisture content (CVMC), bulk EC and temperature (Figure 3A) were installed and connected to data loggers with telemetry so that data from each site could be accessed remotely. Rain gauges were also used to record volumes of irrigation applied and volumes of run-off and in-line water meters connected to data loggers recorded total water use. Irrigation was triggered automatically under the GTR once the coir VMC reached a pre-determined value. This was achieved using GP1 data loggers and SM300 soil moisture probes (Delta-T Devices Ltd) (Figure GS3B). Establishing effective and reliable communication between the GP1 data loggers and the Netafim irrigation rigs at each grower site was carried out by Mr Julian Gruzelier (Eden Irrigation Consultancy Ltd).

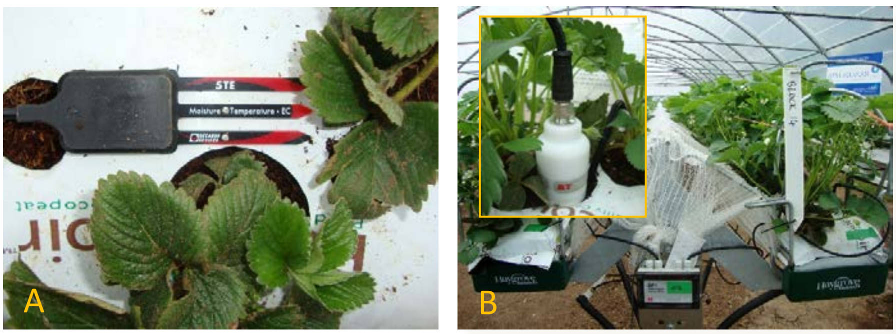

Figure A) The Decagon 5TE sensor used to monitor changes in coir volumetric moisture content, EC and temperature. Photo taken on 15 May 2012. B) The Delta-T GP1 data logger and SM300 probe (inset) used to trigger irrigation automatically once pre-determined values of coir moisture content were reached. Photo taken on 28 June 2012.

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At each of our two grower sites, the GTR was imposed at, or just after, 50% full bloom (second week in June 2012). The lower irrigation set points at each site were selected to ensure that although run-off was eliminated, the coir was still sufficiently wet to provide an effective buffer zone to accommodate any unforeseen interruptions in water supply throughout the experiment. During the small green fruit stage, the aim was to control the frequency of irrigation events in the GTR so that run-off volumes of between 1 and 5% were achieved, irrespective of varying daily evaporative demand. Hourly changes in CVMC, bulk EC and temperature were recorded and used in combination with volumes of irrigation applied and volumes of run-off, to inform the GTR irrigation strategy.

Data from the experiment at New Farm over a 7-day period in June are presented in Figure 4. During this time when midday coir temperature varied between 17 and 27 °C, the frequency of irrigation events was adjusted automatically so that water inputs matched evaporative losses, and CVMC was effectively maintained between 0.6 to 0.65 $m^3\ m^{-3}$.

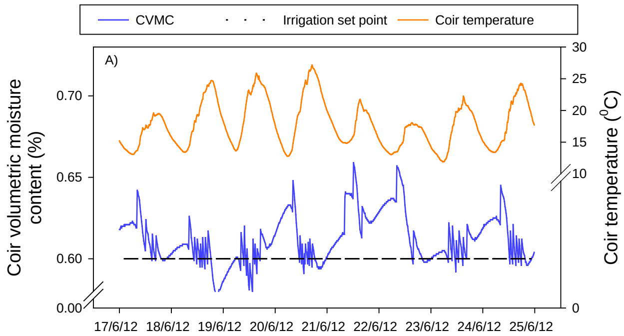

Figure 4. A) Continuous measures of coir volumetric moisture content and temperature during one week in June at New Farm. Irrigation was triggered automatically once the pre-determined value (horizontal dashed line) was reached.

Detailed plant physiological measurements were carried out to determine whether the different irrigation strategies affected plant growth and fruit development.

Changes in CVMC, root zone temperature, dripper inputs and run-off from the experiment at Manor Farm between June and October are presented in Figure GS5.

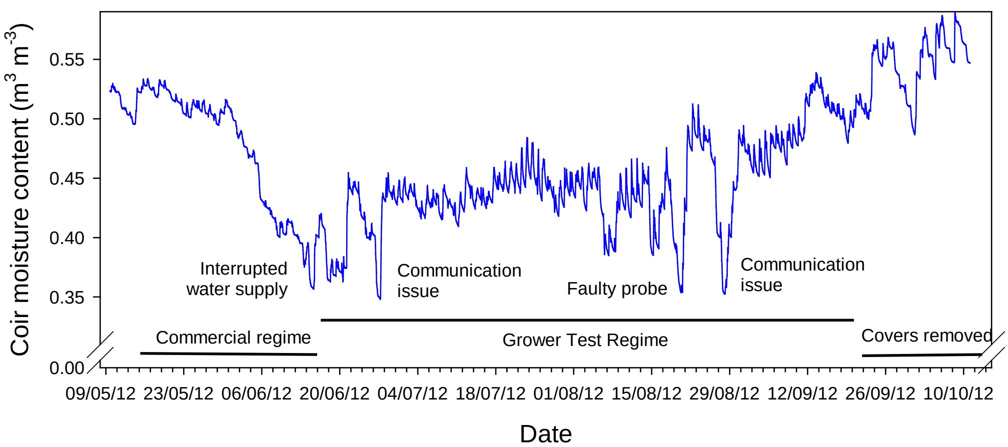

Figure 5. Changes in coir volumetric moisture content and temperature during the experiment at Manor Farm.

Following imposition of the GTR on 16 June, water supply to the trial area was interrupted on two occasions (18 and 26 June) which led to CVMC dropping below the lower irrigation set point. The frequent irrigations needed to restore the CVMC on the 27 June resulted in some run-off (between 2 and 4%) over the following two days. However, from the beginning of July onwards, the CVMC was maintained at a constant value, despite fluctuations in root zone temperature and evaporative demand. The different volumes of water applied per substrate bag on each day (Figure 6A) reflect the differences in daily evaporative demand, with more water needed to maintain CVMC on days with higher evaporative demand. During this time, run-off from the substrate bags under the GTR was eliminated (Figure 6B).

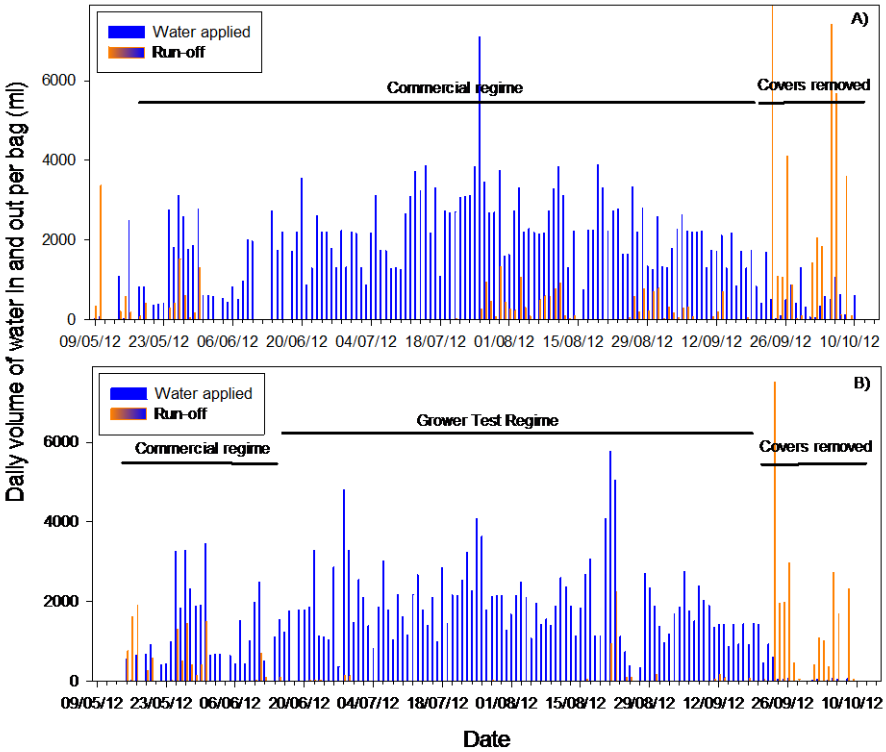

Figure 6. Water inputs and outputs per bag under A) the Commercial Regime and B) the Grower Test Regime at Manor Farm.

Picking began in the first week of July and Class 1, Class 2 and waste fruit were recorded separately from each experimental plot (40 plots at Manor Farm and 32 plots at New Farm). Picking at each of our grower trials continued throughout July until mid-August.

Irrigation water use efficiency

At Manor Farm, from mid-June until mid-August (end of picking), 122 L of water were applied to each substrate bag under the GTR and the volume of run-off was 0.4 L per bag (Table 1). In the Commercial Control treatment, irrigation was scheduled by 'Rad Sum' and 146 L of water per substrate bag were applied over the same period; run-off was 9.2 L per

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bag. Since fertilisers were applied at each irrigation event, a 17% reduction in fertiliser inputs was also achieved under the GTR. Foliar nutrient analysis at the beginning and end of cropping showed no differences between the CC and the GTR treatments.

Table 1. The effects of the two irrigation regimes on yields, fruit quality and water productivity values at Manor Farm.

Irrigation regime	Class 1 yields (g per plant)	Average % BRIX	Average firmness (N)	Volume of water applied per bag (L)	Water Productivity
CC	442	9.2	5.2	146	33
GTR	452	9.5	5.3	122	27

At New Farm Produce, from mid-June until mid-August (end of picking), 102 L of water were applied to each substrate bag under the GTR and the volume of run-off was 1.6 L per bag (Table 2). In the Commercial Control treatment, irrigation was scheduled by a combination of 'Rad Sum' and changes in evaporative demand; 115 L of water per substrate bag were applied over the same period. The volume of run-off was 23 L per bag. These figures

Table 2. The effects of the two irrigation regimes on yields, fruit quality and water productivity values at New Farm.

Irrigation regime	Class 1 yields (g per plant)	Average % BRIX	Average firmness (N)	Volume of water applied per bag (L)	Water Productivity
CC	352	8.8	4.2	115	41
GTR	342	9.1	4.4	102	37

corroborate the view of Stephen McGuffie that the CC was 'run a little wetter' than the GTR. Since fertilisers were applied at each irrigation event, an 11% reduction in fertiliser inputs was also achieved under the GTR. Foliar nutrient analysis at the beginning and end of cropping showed no differences between the CC and the GTR treatments.

Class 1 yields and fruit quality

Class 1 yields from the CC and GTR regimes at Manor Farm were similar and averaged 442 g and 452 g per plant, respectively (Table 1). Class 2 and waste fruit were slightly lower under the GTR but in the trial overall, 97% Class 1 fruit was achieved. Fruit firmness was also similar in berries sampled at the beginning, middle and end of cropping from each

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irrigation regime. Average berry soluble solids contents were also similar but tended to be higher under the GTR towards the end of cropping (GTR = 11.7, CC = 10.7).

Class 1 yields from the CC and GTR regimes at New Farm were similar and averaged 352 g and 342 g per plant, respectively (Table 2). Yield of Class 2 fruit was slightly higher under the GTR. Fruit firmness was also similar in berries sampled at the beginning, middle and end of cropping from each irrigation regime, although values were consistently higher in fruit from the GTR. Average berry soluble solids contents were also similar but were always higher under the GTR.

Water productivity

The efficiency with which irrigation water is used on-farm can be estimated by calculating the Water Productivity (WP) value (the volume of water used to produce 1 kg of Class 1 fruit); a lower value indicates a more efficient use of water. For the GTR at Manor Farm, the WP value calculated from 16 June to 14 August was 27 while for the CC regime, a WP value of 33 was achieved. If the volumes of water used during establishment and after cropping (until the covers were removed in early September) are included, WP values were 50 and 57 for the GTR and CC, respectively. At New Farm Produce the WP value calculated from 16 June to 8 August 2012 for the GTR was 37 while for the CC regime, a WP value of 41 was achieved. The WP values including water used after cropping could not be calculated at New Farm since several large irrigation/fertigation events were applied separately and at different times to plants in the two experimental treatments.

Conclusions

- The aim of this work was to develop and evaluate a system that could be used in commercial substrate production to trigger irrigation automatically, so that coir volumetric moisture contents are maintained between upper and lower set points, irrespective of changing evaporative demand.
- The automated irrigation system was also used to control the volume of run-off at different stages of crop development and/or to eliminate run-off completely.
- The results to date suggest that significant water and fertiliser savings can be achieved in commercial substrate production without affecting berry size, Class 1 yields or fruit quality if irrigation is scheduled to match demand with supply. Water and fertiliser savings of 17% and 11% have been achieved in our experiments at Manor Farm and New Farm Produce respectively, and aspects of berry quality were improved.
- More information is needed on the critical coir EC levels that limit fruit size so that

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water- and fertiliser-savings can also be achieved on sites where irrigation water has a higher background EC.

- The water savings achieved so far in this project are encouraging given that the two growers, Andrew Chesson and Stephen McGuffie, are already ‘water conscious’ and use irrigation water very efficiently.
- New developments in substrate moisture sensor and data logger technology are being developed and will be included in a proposal to continue this work next year on ‘Elsanta’ main season crops at our two grower partner sites.

Knowledge Exchange and Technology Transfer activities

- Project aims, objectives and results were presented in a series of six articles published in the Fruit Grower magazine from May to October 2012.
- The project aims, objectives and results were presented to BIFGA during a visit to EMR, 25 April 2012.
- The potential of using this approach to schedule irrigation automatically to substrate-grown soft fruit crops so that run-off is eliminated was discussed at two Grower Days held at Manor Farm and New Farm Produce, 8 and 11 July, 2013.
- The project aims, objective s and results were presented at the Fruit Focus Forum 2012 at EMR, 25 July 2012.
- The project aims, objectives and results were presented at the Kent Water Summit: Water security for Farmers and Growers, 12 November 2012, EMR.
- The project aims, objective s and results were presented at the HDC / EMRA Soft Fruit Day at EMR, 22 November 2012.
- The project aims, objectives and results were presented during a visit to FAST Ltd 30 January 2013, Faversham, Kent.
- The project aims, objectives and results were presented during a visit to Angus Soft Fruit Ltd, 7 February 2013, Dundee.
- The project aims, objective s and results were presented at the HDC Agronomists’ Day at EMR, 5 March 2012.

Financial benefits for growers

The project aimed to develop practical ways to improve the economic sustainability of soil-less strawberry production by improving both water and fertiliser use efficiencies. We have demonstrated that a ‘closed loop’ system can deliver water and fertiliser savings in commercial production systems. However, current industry ‘standard’, ‘best’ and ‘better’

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practice must be first established before the water and fertiliser use efficiencies delivered in this project can be assessed in a commercial context.

In both commercial trials, five 1.2 L per hour drippers per 1-m substrate bag were used. Some growers are beginning to switch to this system instead of using a 6 L per hour dripper with four irrigation spikes per 1-m bag since water would still be supplied to the majority of the substrate should individual drippers become blocked; these could then be readily and inexpensively replaced. Clearly, the economics of this approach are feasible for commercial production systems.

The reduction in fertiliser use of 17% achieved by one of the participating growers under the GTR could be expected to save around £300/ha/annum. The Rural Business Research (RBR) 2008/2009 Farm Business Survey for Horticulture Production in England reported average annual fertiliser costs (across all specialist glass businesses including soft fruit) of £3,250-£4,500/ha. On this basis, a 20% reduction in fertiliser used could on average therefore save £650-£900/ha. This would cover the costs of the Delta-T GP1 data logger and an SM300 probe; additional one-off costs to cover the connection of the hardware to the commercial fertigation rig would also need to be met.

The RBR 2008/2009 survey reported average annual water costs (across all specialist glass businesses including soft fruit) of £530-£630. This confirms that on average the savings in expenditure on water do not justify expenditure on irrigation scheduling tools. Growers using mains water would be expected to pay significantly more for water and there may then be a significant financial benefit to using less water. The growers involved in this project do not use mains water.

The economic feasibility of installing and running the ‘closed loop’ system developed in this project in commercial production systems would need to be assessed on a case by case basis. Scaling up the relatively small-scale scientific experiments carried out by EMR to several hectares of high value substrate strawberry will require new developments in substrate moisture sensor and data logger technology. The aim is to develop a wireless system capable of controlling multiple zones of different crops or crops at different stages of growth.

Action points for growers

- Employ an irrigation consultant to ensure that current and new irrigation systems are designed correctly to achieve accurate and precise delivery of water and fertilisers.

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- Monitor run-off at different times throughout the day to establish which irrigation events can be reduced to save water and fertilisers.
- Consider using vapour pressure deficits (VPD) to help inform irrigation decisions.
- Use substrate moisture and EC probes to help inform irrigation decisions.
- Consider using five individual 1.2 L h^{-1} drippers per substrate bag to improve the lateral spread of irrigation water and to reduce the impact of blocked emitters on Class 1 yields.

Acknowledgements

We thank Andrew Chesson and his staff at Manor Farm and Stephen McGuffie and his staff at New Farm Produce, and Dr Martin Wood (Earthcare Technical Ltd). We would also like to acknowledge generous ’in-kind’ and cash contributions and technical support from Haygrove Ltd, Botanicoir Ltd, Eden Irrigation Consultancy Ltd, Delta-T Devices Ltd and South East Water Ltd.

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SCIENCE SECTION

Introduction

More efficient use of inputs including water and fertilisers is vital to the future success of UK horticulture. An increasing proportion of soft fruit growers are switching production away from the field into substrates and irrigation is essential to deliver the yields and quality demanded by retailers and consumers. Recent droughts, particularly affecting the south east and east regions, have highlighted the need for growers to use water more efficiently. Predicted increases in agricultural water demand in the 2050s in England and Wales range from 25% to 180% of current usage and growers will be expected to use their irrigation water more efficiently than at present.

Current recommendations to substrate strawberry growers are to irrigate up to 20+% run-off to prevent the development of 'dry spots' and the build-up of solutes (high EC) in the substrate, which eventually limits yields and quality. Nevertheless, this practice results in large losses of water and fertiliser and the Environment Agency are seeking to clarify the effects of these practices on groundwater pollution in the south east. Aspects of fruit quality such as firmness, flavour and shelf-life potential can also be reduced.

Legislation to safeguard resources and limit damage to the environment is already in place and Defra and the Welsh Government are working with the Environment Agency and Ofwat on a project to reform the water abstraction licensing system. Although currently exempt, it is envisaged that drip irrigators will, in future, have to comply with legislation. Produce quality assurance schemes are becoming more exacting in their assessment of whether crops are being grown sustainably and are now requesting supporting data. However, matching plant demand for water with supply can be difficult in changeable summer weather and at different stages of crop development. If growers are to maintain or increase yields against a backdrop of increasing summer temperatures, dwindling water supplies, and governmental demands for greater environmental protection, new production methods that improve water and fertiliser use efficiency and utilise 'best practice' are needed.

Minimising the daily volume of run-off during changeable summer weather can be challenging, especially when substrate EC levels also need to be managed carefully. In previous HDC-funded work (SF 107) carried out by Dr Else's team at East Malling Research (EMR), new techniques to save water and fertiliser use in substrate-grown crops of 'Elsanta' and 'Sonata' were developed. An irrigation scheduling regime that matched water supply to

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demand, thereby eliminating run-off, was designed using irrigation set points based on plant responses to decreasing substrate moisture contents. In scientific experiments, water and fertiliser savings of 15% for ‘Elsanta’ and 45% for ‘Sonata’ were achieved without sacrificing any Class 1 yield, compared to a commercial regime where run-off averaged 20% over the season. Aspects of fruit quality were also improved, compared to ‘commercial controls’. This irrigation/fertigation strategy needed to be tested in commercial grower experiments to help ensure relevance to the industry and to take account of differences in water quality and background EC.

The aim of the project was to develop and test an irrigation scheduling tool that triggers irrigation automatically, according to plant water use so that water demand is matched with supply. EMR carried out experiments in commercial substrate systems at Andrew Chesson’s farm (Manor Farm, S.H. Chesson Partnership, Oldbury, Ightham, Kent) and at Stephen McGuffie’s farm (New Farm Produce Ltd, Elmhurst, Lichfield, Staffordshire). We tested whether, by adjusting the irrigation set points, it was possible to reduce or eliminate run-off of water and fertilisers, without reducing Class 1 yields or quality.

Materials and Methods

Plant establishment

Experiments were carried out at Manor Farm and at New Farm. At each site, the growers’ usual method of irrigation scheduling (Commercial Control) was compared with a Grower Test Regime (GTR) that has been developed at EMR over several years with Defra- and HDC funding. ‘Elsanta’ were planted into coir bags in late April and early May at planting densities of ten and eight plants per 1 m coir bag at Manor Farm and New Farm, respectively. During establishment, all plants were irrigated and fertigated according to usual grower practice. The trial at Manor Farm was covered in the last week of May 2012 and so the frequent rainfall during spring 2012 helped to reduce ‘blue water’ inputs (fresh water from surface or groundwater sources). The trial at New Farm Produce was covered from planting and so irrigation was essential to aid establishment.

Experimental design

Each trial was set up in a fully replicated randomised block design to ensure statistical rigour; to achieve this, two separate header pipes had been installed at each site so that irrigation to the CC and GTR treatments could be applied independently. At Manor Farm, the experimental site comprised of four tunnels each containing five rows of substrate crops. Each 40-m-long row consisted of an experimental block which was divided in to two

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20-m-long plots. There were 20 experimental blocks for each irrigation treatment with 19 residual degrees of freedom (Figure 7).

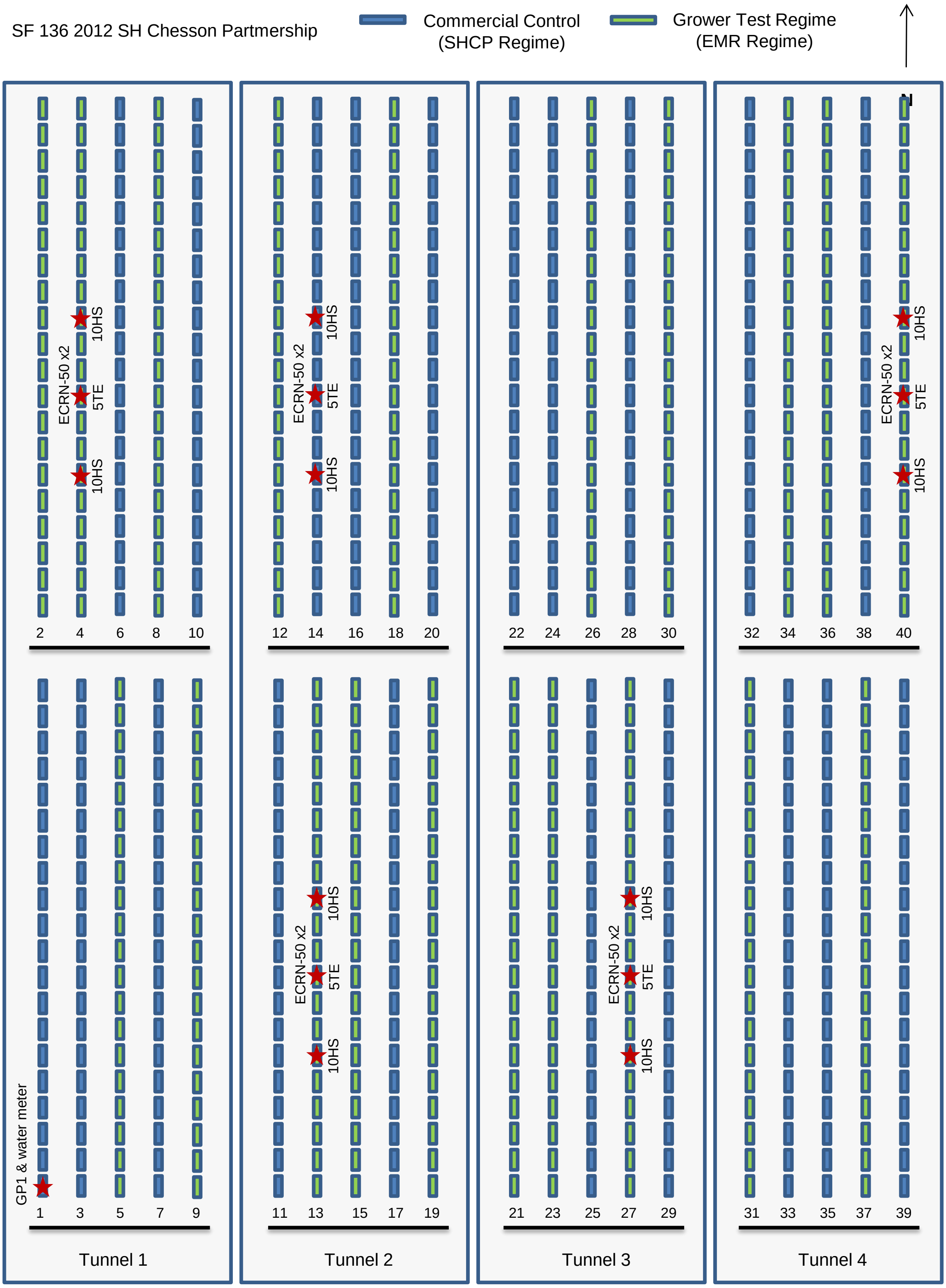

Figure 7. The experimental design for the trial at Manor Farm, S.H. Chesson Partnership. The location of moisture probes and rain gauges is also shown.

At New Farm, the experimental site consisted of two tunnels each containing four double rows of substrate crops. Each 21-m-long row consisted of an experimental block which was

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divided in to a 10 m- and an 11 m-long plot. There were 16 experimental blocks for each irrigation treatment with 15 residual degrees of freedom (Figure 8).

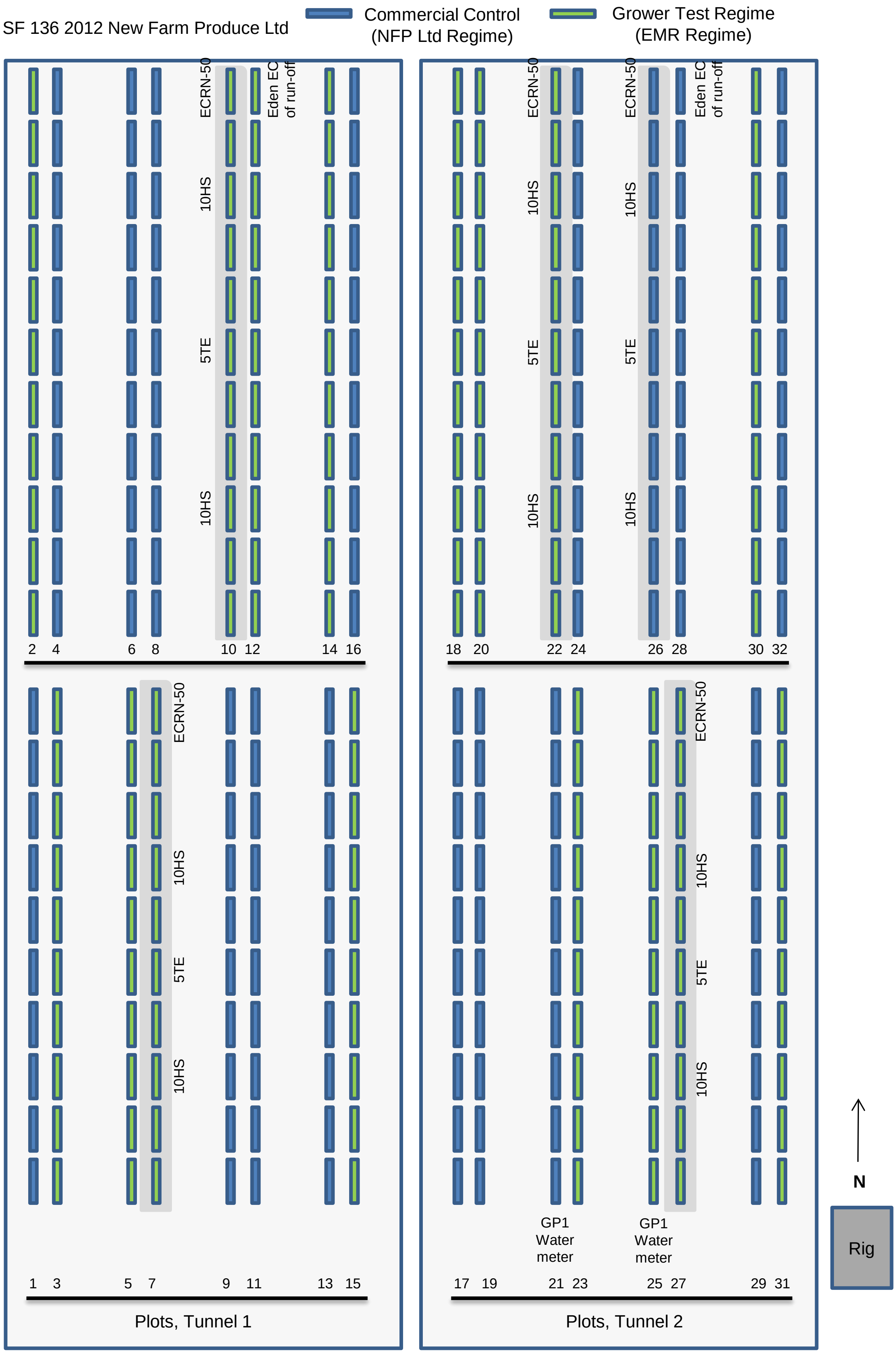

Figure 8. The experimental design for the trial at New Farm, New Farm Produce Ltd. The location of moisture probes and rain gauges is also shown.

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site, the GTR was imposed at, or just after, 50% full bloom (second week in June 2012). The lower irrigation set points at each site were selected to ensure that, although run-off was eliminated, the coir was still sufficiently wet to provide an effective buffer zone to accommodate any unforeseen interruptions in water supply throughout the experiment. This was achieved using GP1 data loggers and SM300 soil moisture probes (Delta-T Devices Ltd) (Figure 9) to trigger irrigation once pre-determined coir volumetric moisture contents (CVMC) were reached. Effective and reliable communication between the GP1 data loggers and the Netafim irrigation rigs at each trial site was established and maintained by Mr Julian Gruzelier (Eden Irrigation Consultancy Ltd).

Figure 9. The SF 136 trial site at New Farm (New Farm Produce Ltd, Elmhurst, Lichfield, Staffordshire). Inset: the soil moisture probe and data logger used to trigger irrigation automatically. Photo taken on 10 July 2012.

Volumetric substrate moisture content and EC

Changes in CVMC were logged continuously using Decagon 10HS probes and EM50G data loggers with telemetry. Substrate EC and temperature was also logged continuously using Decagon 5TE probes and Decagon ECRN-50 rain gauges were used to record volumes of irrigation applied and volumes of run-off. Data were downloaded remotely, put into spread sheets and analysed at least two times per day throughout the experiment. In-line water meters connected to data loggers recorded total water use in each irrigation regime. Manual measurements of VCMC and substrate EC at several positions within each substrate bag were also made each week with a Delta-T Devices ‘WET’ sensor by visiting EMR staff (Figure 10).

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Figure 10. Spot measurements of coir volumetric moisture content, bulk EC and temperature were made weekly with a Delta-T 'WET' sensor. Photo taken on 26 July 2012.

During the small green fruit stage, the aim was to control the frequency of irrigation events in the GTR so that run-off volumes of between 1 and 5% were achieved, irrespective of varying daily evaporative demand. Hourly changes in CVMC, bulk EC and temperature were recorded and used in combination with volumes of irrigation applied and volumes of run-off, to inform the GTR irrigation strategy. At the beginning of fruit ripening, the lower irrigation set points was reduced slightly at each site to try to eliminate run-off during cropping.

Leaf tissue and substrate nutrient status

Leaf samples were taken from each of irrigation regimes at each site for nutrient analysis at the beginning, middle and towards the end of cropping to determine whether the reduced water and fertiliser inputs under the GTR regimes affected plant mineral content.

Measurement of physiological responses

All routine measurements were carried out on one plant in a randomly chosen bag in each experimental plot; there were 20 and 16 replicate plants per treatment at Manor Farm and at New Farm, respectively. Measurements were made over eight consecutive weeks from

Figure 11. Measurements of the effects of the two irrigation regimes on A) midday leaf water potential and B) stomatal conductance in the experiment at New Farm. Photo taken on 19 June 2013.

21 June until mid-August 2012 (Figure 11). Midday leaf water potential (ψ_L) was measured weekly; for each plant, one young, fully-expanded, trifoliate leaf was excised using a sharp blade and sealed in to a plastic bag containing a sheet of damp tissue paper. Within 30 s of excision, ψ_L was determined with a Skye SKPM 1400 pressure bomb (Skye Instruments Ltd, UK). Stomatal conductance (g_s) of one young, fully-expanded leaf per experimental plant was measured with a steady-state porometer (Leaf porometer SC-1, Decagon Devices Ltd.). Rates of photosynthesis of fully expanded leaves were measured using a portable infra-red gas analyser (CIRAS-1, PP-systems) with an additional light source powered by a car battery on five occasions during fruit development and cropping.

Leaf extension was determined by measuring the length of the middle trifoliate leaf blade of young expanding leaves weekly until maturity; new expanding leaves were then labelled and measured. In total, leaf extension of three expanding leaves was measured throughout the season.

Changes in primary, secondary and tertiary fruit volume were measured weekly during development to determine whether the different irrigation and fertigation regimes affected the rate of fruit expansion (Figure 12). The diameter of labelled fruit was measured twice at diametrically opposed positions on the shoulder and combined with length measurements to estimate fruit volume; for this purpose, fruit were assumed to be conical.

Figure 12. Measuring the effects of the two irrigation regimes on the rate of fruit expansion. Photo taken on 19 June 2013

Fruit harvesting, grading and sampling for quality analyses

Ripe fruit were harvested and pooled from each experimental plot by the picking teams at Manor Farm and New Farm. Ripe fruit were first harvested at Manor Farm on 5 July 2012 and were picked twice-weekly until 14 August 2012. At New Farm, picking began on 7 July and continued until 8 August 2012. All ripe fruit were harvested and graded into commercial

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Class 1 fruit, Class 2 fruit and waste fruit (mis-shapes, bid damage, splits and rots).

Punnets of fruit were collected from the pack houses on four occasions throughout cropping and transported to EMR for analyses. The average fresh weight of fruit was recorded using a portable balance (ScoutPro 4000, Ohaus UK Ltd, UK). Berry firmness of one primary or secondary fruit was measured at two diametrically opposed points using a hand-held penetrometer (HPE II, Bureiss Prüfgerätebau, GmbH) fitted with a 0.5 cm^2 anvil. Berry SSC was measured with a digital refractometer (Palett 100, Atago & Co. Ltd, Tokyo, Japan).

Calculation of water productivity

The total volume of irrigation water applied during the experiments from 16 June until 14 August 2012 was calculated for each irrigation regime at both experimental sites. The volume of irrigation water (L) used to produce a standard mass of class 1 fruit (1 kg) was also calculated. This is an estimate of water productivity (WP) and a lower value implies a more productive use of water.

Statistical analyses

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

Results

Automated irrigation scheduling

Irrigation was scheduled automatically using the Delta-T GP1 and SM300 soil moisture probes. The lower irrigation set points were adjusted throughout the season to control the percentage run-off. Data from the experiment at New Farm over a 7-day period in June are presented in Figure 13A. During this time, when midday coir temperature varied between 17 and 27 °C, the frequency of irrigation events was adjusted automatically so that water inputs were similar to evaporative losses and CVMC was effectively maintained between 0.6 to 0.65 $m^3\ m^{-3}$. The lower irrigation set point was 0.6 $m^3\ m^{-3}$ during this time which, combined with the irrigation delivery volume of 276 mL per event, effectively maintained the CVMC just below bag capacity so that the percentage run-off averaged between 1 and 4% (Figure 13B).

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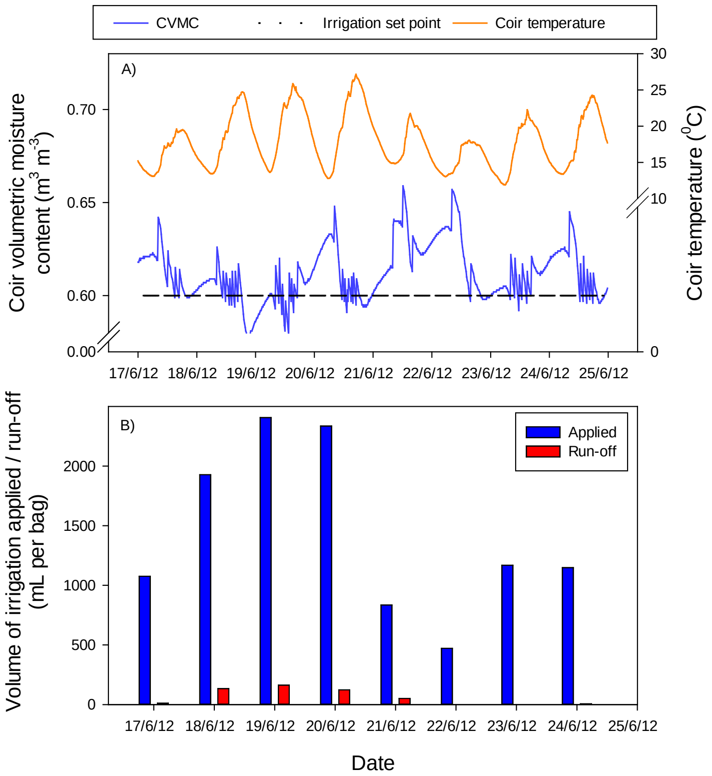

Figure 13. A) Changes in coir volumetric water content and temperature over a 7-day period in June. The horizontal dashed line is the irrigation lower set point. B) Volume of irrigation applied and run-off per bag during the same 7-day period as in A).

Volumetric moisture contents and substrate EC

Changes in CVMC, root zone temperature, dripper inputs and run-off from the experiment at Manor Farm between June and October are presented in Figure 5. Following imposition of the GTR on 16 June, water supply to the trial area was interrupted on two occasions (18 and 26 June) which led to CVMC dropping below the lower irrigation set point. The frequent irrigations needed to restore the CVMC on 27 June resulted in some run-off (between 2 and 4%) over the following two days. However, from the beginning of July onwards, the CVMC was maintained at a constant value, despite fluctuations in root zone temperature and evaporative demand. The different volumes of water applied per substrate bag on each day (Figure GS6A) reflect the differences in daily evaporative demand, with more water needed to maintain CVMC on days with higher evaporative demand. During this time, run-off from the substrate bags under the GTR was eliminated (Figure 6B).

Changes in CVMC, root zone temperature, dripper inputs and run-off from the experiment at New Farm between June and November are presented in Figure 14.

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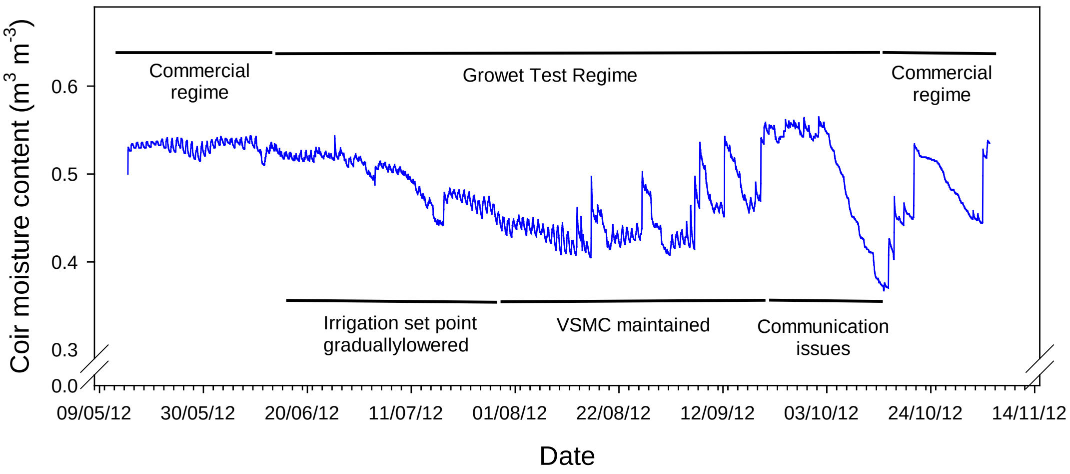

Figure 14. Changes in coir volumetric moisture content during the experiment at New Farm. The values are means from seven Decagon 10HS probes.

Following imposition of the GTR on 16 June, the lower irrigation set point was lowered gradually over the next few weeks to ensure that run-off was first reduced, and then eliminated. Several issues with the newly installed irrigation system in the GTR meant that some plants showed signs of wilting at times of high evaporative demand in blocks furthest from the irrigation rig. Our measurements indicated that the plot in which the SM300 probe was located consistently received a greater volume of irrigation water than other plots at each irrigation event (385 vs 235 mL) and so the substrate bag in which the SM300 probe was located ceased to be representative of the rest of the crop. Consequently, irrigation was not triggered in response to increasing evaporative demand and so the average CVMC began to fall during early July 2012. The SM300 probe was relocated on 17 July 2012 to a more representative bag and the lower irrigation set point was adjusted again to control the frequency of irrigation events. Run-off from the bags under the GTR was largely eliminated throughout cropping (Figure 15A). Communication issues and problems with consistent water delivery resulted in temporary substrate drying after cropping and several lengthy irrigation events were applied to raise CVMC (Figure 15A), which temporarily increased the volume of run-off. Sufficient irrigation was applied to the CC to ensure a degree of run-off during and after cropping (Figure 15B).

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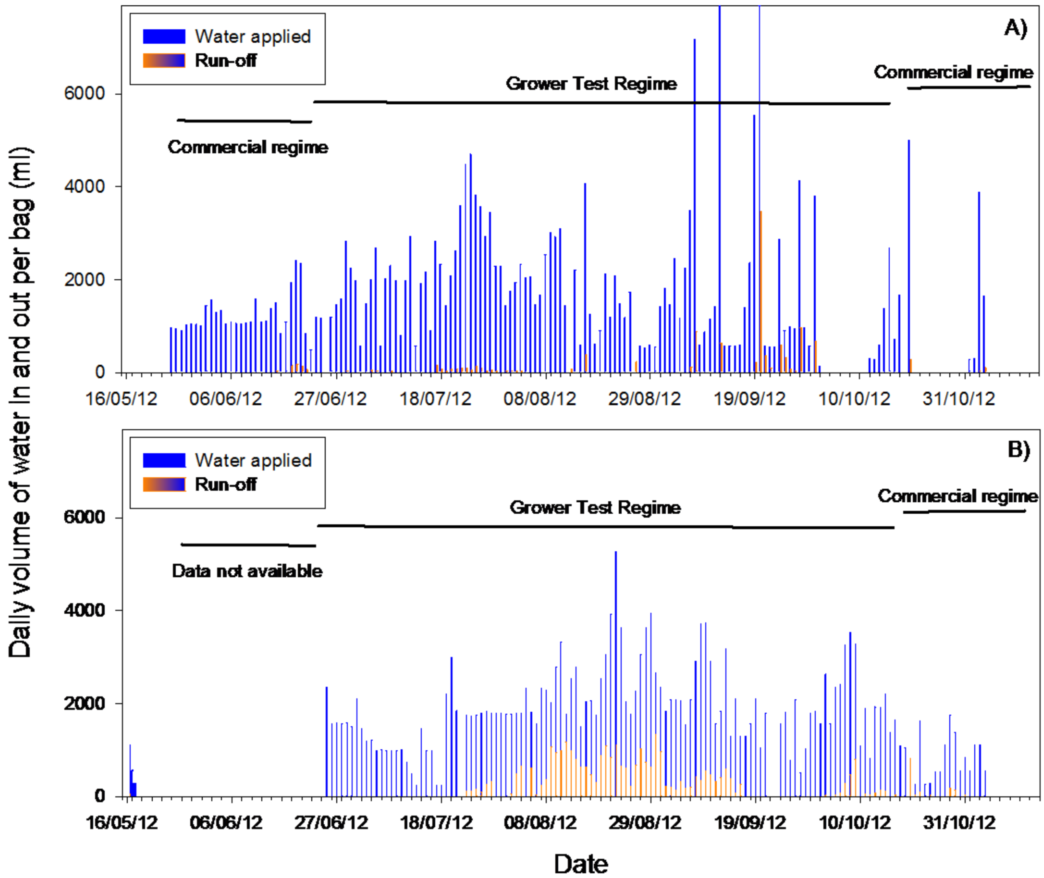

Figure 15. Water inputs and outputs per bag under A) the Grower Test Regime and B) the Commercial Regime at New Farm. No data are available from the first few weeks of the CC regime.

Class 1 yields and fruit quality

Class 1 yields from the CC and GTR regimes at Manor Farm were similar and averaged 442 g and 452 g per plant, respectively (Table 1). Class 2 and waste fruit were slightly lower under the GTR but in the trial overall, 97% Class 1 fruit was achieved. Fruit firmness was also similar in berries sampled at the beginning, middle and end of cropping from each irrigation regime. Average berry soluble solids contents were also similar but tended to be higher under the GTR towards the end of cropping (GTR = 11.7, CC = 10.7).

Class 1 yields from the CC and GTR regimes at New Farm were similar and averaged 352 g and 342 g per plant, respectively (Table 2). Yield of Class 2 fruit was slightly higher under the GTR. Fruit firmness was also similar in berries sampled at the beginning, middle and end of cropping from each irrigation regime, although values were consistently higher in fruit from the GTR. Average berry soluble solids contents were also similar but were always higher under the GTR.

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Water productivity

At Manor Farm, from mid-June until mid-August (end of picking), 122 L of water were applied to each substrate bag under the GTR and the volume of run-off was 0.4 L per bag (Table 1). In the CC treatment, irrigation was scheduled by 'Radiation Sum' and 146 L of water per substrate bag were applied over the same period; run-off was 9.2 L per bag. Since fertilisers were applied at each irrigation event, a 17% reduction in fertiliser inputs was also achieved under the GTR. Foliar nutrient analysis at the beginning and end of cropping showed no differences between the CC and the GTR treatments. When the volumes of water applied during establishment, cropping and during the post-harvest period were calculated, 224 and 251 L of water were applied to the GTR and the CC regimes, respectively. Thus, WP values over the first year of production in the trial at Manor Farm were 50 and 57 for the GTR and CC regimes, respectively. The average industry WP value for 60-day substrate strawberry crops is not yet known.

At New Farm, from mid-June until mid-August (end of picking), 102 L of water were applied to each substrate bag under the GTR and the volume of run-off was 1.6 L per bag (Table 2). In the CC treatment, irrigation was scheduled by a combination of 'Radiation Sum' and changes in Vapour Pressure Deficit (VPD); 115 L of water per substrate bag were applied over the same period. The volume of run-off was 23 L per bag. These figures corroborate the view of Stephen McGuffie that the CC was 'run a little wetter' than the GTR. Since fertilisers were applied at each irrigation event, an 11% reduction in fertiliser inputs was also achieved under the GTR. Foliar nutrient analysis at the beginning and end of cropping showed no differences between the CC and the GTR treatments. It was not possible to calculate the WP values over the first season of production since several large irrigation/fertigation events were applied separately and at different times to plants in the two irrigation treatments.

Discussion

Substrate growing is a major capital investment and yet irrigation/fertigation decisions are not often based on scientific evidence. The aim of this work was to develop and evaluate a system that can be used in commercial substrate production to trigger irrigation automatically, so that CVMC are maintained between upper and lower set points, irrespective of changing evaporative demand. This required integration of scientific data logger and controller units with commercial irrigation/fertigation rigs so that irrigation could be triggered automatically once irrigation set points were reached. The automated irrigation

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system was also used to control the volume of run-off at different stages of crop development and/or to eliminate run-off completely.

The results to date suggest that significant water and fertiliser savings can be achieved in commercial substrate production without affecting berry size, Class 1 yields or fruit quality if irrigation is scheduled to match demand with supply. Water and fertiliser savings of 17% and 11% have been achieved in our experiments at Manor Farm and New Farm respectively, and aspects of berry quality were improved. The water savings achieved in this project are encouraging given that the two growers, Andrew Chesson and Stephen McGuffie, are already 'water conscious' and use irrigation water very efficiently.

Although the automated irrigation scheduling tool effectively maintained CVMC between upper and lower set points at each site for much of the growing season, the reliance on a single value of CVMC taken from what was assumed to be a representative position in a coir bag meant that data had to be downloaded and analysed several times each day to ensure that any issues were identified and dealt with promptly. On one occasion at New Farm, the SM300 probe had to be relocated to a more representative plant. At Manor Farm, the original plant under which one of the SM300 probes was placed died and therefore, very little change in CVMC was recorded and therefore, the lower irrigation set point wasn't reached and the rest of the crop under the GTR began to dry down. Since data was being downloaded and analysed twice a day, this was noted almost immediately and the probe was repositioned. Nevertheless, these episodes highlight the potential difficulties in scaling up the relatively small-scale scientific experiments carried out by EMR to several hectares of high value substrate strawberry. New developments in substrate moisture sensor and data logger technology are needed before the closed loop system can be implemented to manage irrigation reliably in large-scale commercial substrate production. The aim is to develop a system capable of controlling multiple zones of different crops or crops at different stages of growth. The new GP2 Advanced Logger and Controller from Delta-T Devices will facilitate the development of a closed-loop irrigation and fertigation control system, capable of averaging data from up to 12 sensors and disregarding data from malfunctioning soil moisture probes. Telemetry would enable data from the Netafim irrigation rig to be accessed remotely. This farm-scale automatic irrigation scheduling system would help to deliver the improvements in water and fertiliser use efficiency in substrate soft fruit production. Such a system is currently being developed and tested at EMR.

The challenge now is to encourage grower uptake of these scientifically-derived irrigation

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scheduling strategies, to help improve on-farm water use efficiency. The more 'water conscious' growers already have the systems and approaches in place to deliver high on-farm water use efficiencies and the recent benchmarking work carried out by EMR and Berry Gardens Growers Ltd for soil-grown crops needs to be extended to substrate crops to help identify the decision-making processes that underpin effective irrigation water management. Growers who currently exemplify industry irrigation 'best practice' need to be identified so that their philosophy can be promoted to help achieve the sustainable use of irrigation water.

Further research is needed to test whether the water-saving irrigation strategies can be implemented on grower sites with poor quality irrigation water (high background EC) or increasingly saline irrigation water (due to salt water ingression) without reducing marketable yields or quality. More information is needed on the critical coir EC levels that limit fruit size.

Conclusions

- The aim of this work was to develop and evaluate a system that could be used in commercial substrate production to trigger irrigation automatically, so that coir volumetric moisture contents are maintained between upper and lower set points, irrespective of changing evaporative demand.
- The automated irrigation system was also used to control the volume of run-off at different stages of crop development and/or to eliminate run-off completely.
- The results to date suggest that significant water and fertiliser savings can be achieved in commercial substrate production without affecting berry size, Class 1 yields or fruit quality if irrigation is scheduled to match demand with supply. Water and fertiliser savings of 17% and 11% have been achieved in our experiments at Manor Farm and New Farm respectively, and aspects of berry quality were improved.
- More information is needed on the critical coir EC levels that limit fruit size so that water- and fertiliser-savings can also be achieved on sites where irrigation water has a higher background EC.
- The water savings achieved so far in this project are encouraging given that the two growers, Andrew Chesson and Stephen McGuffie, are already 'water conscious' and use irrigation water very efficiently.
- New developments in substrate moisture sensor and data logger technology are being developed.

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Knowledge Exchange and Technology Transfer activities

- Project aims, objectives and results were presented in a series of six articles published in the Soft Fruit Grower magazine from May to October 2012.
- The project aims, objectives and results were presented to BIFGA during a visit to EMR, 25 April 2012.
- The potential of using this approach to schedule irrigation automatically to substrate-grown soft fruit crops so that run-off is eliminated was discussed at two Grower Days held at Manor Farm and New Farm on 8 and 11 July 2012 respectively.
- The project aims, objectives and results were presented at the Fruit Focus Forum 2012 at EMR on 25 July 2012.
- The project aims, objectives and results were presented at the Kent Water Summit: Water Security for Farmers and Growers on 12 November 2012 at EMR.
- The project aims, objectives and results were presented at the HDC / EMRA Soft Fruit Day at EMR on 22 November 2012.
- The project aims, objectives and results were presented during a visit to FAST Ltd , Faversham, Kent on 30 January 2013.
- The project aims, objectives and results were presented during a visit to Angus Soft Fruit Ltd, Dundee on 7 February 2013.
- The project aims, objectives and results were presented at the HDC Agronomists' Day at EMR on 5 March 2013.

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