Project title:	Improving the consistency of fruit quality in substrate-grown June-bearer strawberry varieties under precision production systems
Project number:	SF 152
Project leader:	Drs Eleftheria Stavridou and Mark A. Else
Report:	Annual report, June 2016
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Key staff:	Mike Davies, Clare Hopson, June Taylor, Veronica Martinez, Carlos Angulo
Location of project:	NIAB EMR (formerly East Malling Research)
Industry Representative:	Laurie Adams, Hall Hunter Partnership
Date project commenced:	1 April 2014
Date project completed (or expected completion date):	31 March 2017

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.

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Signature .. Date 13 June 2016

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GROWER SUMMARY

Headline

- Transient rises in coir pore E.C. to 3.5 mS cm^{-1} did not affect marketable yields and fruit quality

Background and expected deliverables

Intensive soft fruit substrate production systems incur high initial financial investments and require careful management to ensure quality is predictable, consistent and controllable. Growers are strongly advised to irrigate to achieve 10-25% run-off to prevent the accumulation of damaging ‘salts’ or ‘ballast ions” within the substrate. Nevertheless, the consistency of supply of high quality berries varies between growers and between successive harvests and more precise management of water and fertiliser inputs is needed to improve consistency of yields and quality.

The removal of the exemption for trickle irrigators, the on-going Abstraction Licence Reform and the UK’s recent failure to meet the objectives set out in the Water Framework Directive around achieving ‘good quality status’ of our water bodies, mean that on-farm water and fertiliser use efficiencies must be improved. AHDB-funded research conducted at EMR (SF 107) and on commercial strawberry grower sites (SF 136) showed that run-off can be eliminated without affecting Class I yields, and aspects of fruit quality were improved. On-going work on precision fertigation in NIAB EMR’s IUK projects has confirmed that run-off can be reduced or eliminated whilst maintaining or improving marketable yields and consistency of fruit quality in several proprietary varieties. Despite the obvious benefits of our research, concern over perceived problems associated with increased substrate electrical conductivity (E.C.) is limiting growers’ uptake of the new water- and fertiliser-saving techniques developed at East Malling. To help growers gain confidence in reducing water and fertiliser inputs, the critical coir pore E.C. values and the contributory ions that limit fruit size and quality in modern commercial cultivars (cvs) such as “Sonata” and “Vibrant” need to be determined. These values can then be used with the automated ‘flushing’ technologies being developed in IUK project 101623 to control coir pore E.C. more precisely.

There is an also opportunity to improve tolerance to high substrate E.C. by manipulating ammonium-N ($N\text{-}NH_4$) and nitrate-N ($N\text{-}NO_3$) ratios and this approach can also improve fruit number, berry firmness, soluble solids content and shelf-life potential. Manipulating the ratio of N-NO_3 to N-NH_4 would be of particular benefit in cultivars such as "Sonata" where berries can be soft and vulnerable to bruising. Despite positive reports in the scientific literature, the UK soft fruit industry is wary of using ammonium nitrate as a major source of N. Currently, ammonium nitrate is used to provide N-NH_4 during fruit development, but is usually eliminated two weeks before picking as it can lead to unacceptable softening and subsequent poor shelf-life. The potential of altering N nutrition to improve both tolerance to high concentrations of 'ballast' ions in the substrate (high E.C.) and fruit yields and quality will be tested in Project Year 3.

The project aims are:

1. To improve consistency of fruit quality and reduce unmarketable/waste fruit in "Sonata" and "Vibrant"
2. To develop precision fertigation techniques to increase resource use efficiency and environmental performance in substrate soft fruit production

Expected deliverables from this work include:

- The effects of over-watering and over-feeding on consistency of fruit quality in "Sonata" and "Vibrant"
- New grower guidelines for the precision production of substrate-grown "Sonata" and "Vibrant"
- Identification of coir pore E.C. / ion' concentrations that limit fruit size and quality
- The potential of manipulating N nutrition to improve tolerance to high coir pore E.C.

Summary of the project and main conclusions

In the second year of the project, coir pore E.C. values that limit marketable yields in 60-day substrate-grown "Sonata" and "Vibrant" were identified.

Experimental design

"Sonata" and "Vibrant" plants were grown in 3 litre coir pots, 2 crowns per pot, in the GroDome (controlled environment) facility at NIAB EMR (Figure 1). Three E.C. treatments were applied: (i) EC2.5 where coir pore E.C. was kept below 2.5 mS cm^{-1}; (ii) EC3.5 where the coir pore E.C. was raised gradually to 3.5 and maintained between 3.5 and 4.0 mS cm^{-1}; (iii) EC4.5 where the pore coir E.C. was raised gradually to 4.5 and maintained between 4.5 and 5.0 mS cm^{-1}.

To control the build-up of coir pore E.C. in the different treatments, two feed solutions were applied; a commercial standard feed in which E.C. was maintained between 1.6 - 1.8 mS cm^{-1}, and a high E.C. feed in which E.C. was adjusted between 2.8 – 4.0 mS cm^{-1} to achieve the desired coir pore E.C. value. During plant establishment, the standard commercial feed was applied to all plants. The EC3.5 and EC4.5 treatments were then imposed on some plants by increasing the E.C. of the feed solution first to 2.8 mS cm^{-1}, then by gradually raising the feed E.C to 4.0 mS cm^{-1} to increase the rate of E.C. build-up during cropping. Once the target coir pore E.C. value was reached, the standard commercial feed was applied to maintain the coir pore E.C. within the desired ranges.

Fertigation to “Vibrant” and “Sonata” was scheduled automatically using the irrigation set points derived in Project Year 1 and the precision fertigation approach developed at East Malling. The frequency of irrigation events was controlled by measuring the average coir volumetric moisture content (CVMC) using three SM150 sensors connected to a Delta-T GP2 Advanced Datalogger (Delta-T Devices Ltd). Once pre-determined values of CVMC were reached, irrigation was triggered automatically. In both “Vibrant” and “Sonata”, the average CVMC in all the treatments was maintained between 48% and 65% throughout the experiment. The duration of irrigation events was adjusted to reduce run-off.

Figure 1. “Sonata” and “Vibrant” plants were grown in a controlled environment in the GroDome at NIAB EMR. Photo taken on 20 May 2016

Spot measurements of CVMC, pore E.C. and coir temperature were made using a WET sensor and a hand-held HH2 unit (Delta-T Devices Ltd). Irrigation water inputs and run-off were measured with rain gauges connected to EM50G data loggers with telemetry (Decagon Devices Ltd). Leaf and coir samples were collected and analysed to determine the effects of the different E.C. treatments on plant nutrient status. Routine physiological measurements were carried out on twelve replicate plants per cultivar in each experiment. Stomatal conductance, midday stem water potential, rate of photosynthesis and leaf and fruit growth rate were measured at intervals throughout the vegetative and cropping stages in each cultivar.

Results

Coir Volumetric Moisture Content, pore E.C. and nutrient accumulation

In both “Vibrant” and “Sonata”, the average CVMC in the treatments was maintained between 48% and 65% throughout the experiment.

In the EC2.5 treatment, coir pore E.C. was maintained below 3.5 mS cm^{-1} throughout development and cropping in both cultivars. In “Vibrant”, the coir pore E.C. in the EC3.5 treatment reached the target value on 20 April 2016, and coir pore E.C. was generally maintained between 3.0 and 3.5 mS cm^{-1} throughout cropping. In the EC4.5 treatment, the highest coir pore E.C. value that could be achieved was 3.9 mS cm^{-1} on 4 May 2016.

In “Sonata”, the coir pore E.C. in the EC3.5 treatment reached the target value on 13 April 2016, and was maintained between 3.5 to 4.0 mS cm^{-1} until measurements made on 3 May 2016 indicated that the coir pore E.C. had risen to 4.5. Pots were then flushed with the commercial feed solution to reduce coir pore E.C.; values fell temporarily to 2.5 mS cm^{-1} and returned to target values by 13 May 2016. In the EC4.5 treatment, the coir pore E.C. reached the target value on 27 April 2016 and was maintained between 4.0 and 5.0 mS cm^{-1} for the remainder of the experiment.

Effect of E.C. treatments on plant physiological responses

Midday stem water potential is a sensitive indicator of limited substrate water availability and other forms of plant stress and can be used to detect the very early stress-induced changes in shoot water balance. Although such values may be significantly lowered, important agronomic traits such as fruit expansion and the accumulation of precursors for important flavour compounds are often only detected as the stress intensifies. A slight but statistically significant decrease in midday stem water potential in both cultivars was detected in plants receiving the EC4.5 treatment on 22 March 2016. At this time, the coir pore E.C. of the EC2.5 plants was below 2.0 mS cm^{-1}, but the coir of those in the 3.5 and 4.5 treatments had only reached 2.5 mS cm^{-1} (Figure 2). In both cultivars, values of midday stem water potential continued to diverge in the EC3.5 and EC4.5 treatments. In “Sonata”, photosynthesis and stomatal conductance were unaffected by the coir pore E.C. values that were reached in these experiments. In “Vibrant”, photosynthesis and stomatal conductance was not affected by transient increases in coir pore E.C to 3.5 mS cm^{-1} but after prolonged exposure to this and higher coir pore E.C. values, both parameters were reduced significantly compared to values measured in plants receiving the EC2.5 treatment. Fruit and leaf extension rates were not affected by the E.C. treatments in either cultivar.

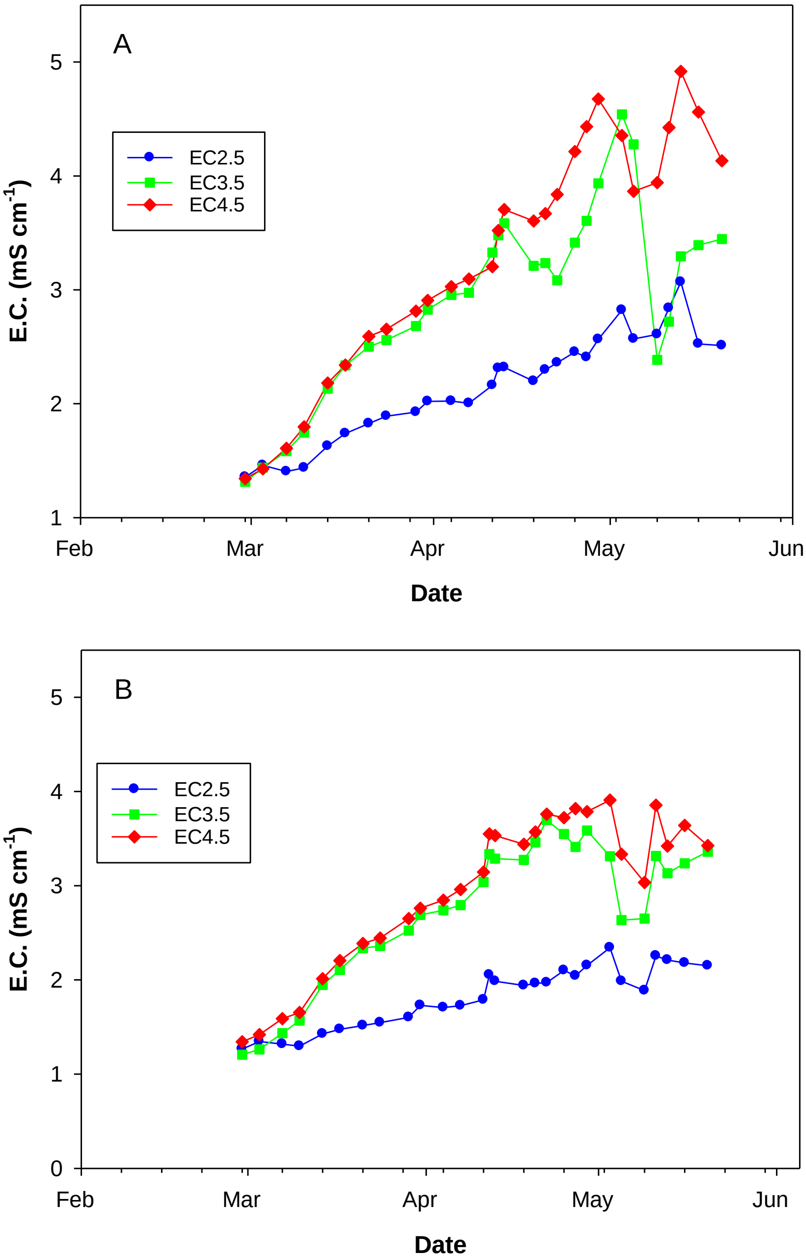

Figure 2. Coir pore E.C. built-up in ‘Sonata’ (A) and ‘Vibrant’ (B) plants under the three E.C. treatments

Effects of E.C. treatments on marketable yield and fruit quality

High E.C. levels decreased the total and Class I yields. The reduction was attributable to fruit size as well as a decrease in berry number (Table 1). No statistically significant differences in berry quality attributes including firmness and soluble solids content (SSC [%

BRIX]) were detected (Table 1).

Table 1. The effects of the three E.C. treatments on Class I yields and fruit quality components of "Sonata" and "Vibrant".

Treatment	"Sonata"			"Vibrant"		
	Class I yield (g plant^{-1})	Average BRIX (%)	Average Firmness (N)	Class I yield (g plant^{-1})	Average BRIX (%)	Average Firmness (N)
EC2.5	529.4a*	7.9a	2.6a	315.8a	7.4a	3.5a
EC3.5	476.1ab	8.1a	2.7a	295.0ab	8.0a	3.7a
EC4.5	419.3b	7.9a	2.9a	197.0b	8.1a	3.9a

*means followed by the same letter are not significantly different (p=0.05)

Leaf fresh and dry weight

In both "Sonata" and "Vibrant", leaf fresh weight (F.W.) and dry weight (D.W.) at the end of the experiments were reduced in plants under the EC3.5 and EC4.5 treatments when compared to those in the EC2.5 treatment. This reduction was most marked in "Vibrant" with a 22% and 49% reduction in DW of plants in the EC3.5 and EC4.5 treatments, respectively. In "Sonata", reductions in DW of 13% and 23% were recorded for plants in the EC3.5 and EC4.5 treatments, respectively, compared to those in the EC2.5 treatment.

Financial benefits

The project aims to improve the economic sustainability of substrate strawberry production by improving both water and nutrient use efficiencies and improving tolerance to higher core pore E.C. values. Savings associated with a 30-40% reduction in mains water and fertiliser costs are likely to be increasingly significant, provided that yields, quality, and shelf-life are either maintained or improved. Evidence from other on-going projects suggests that avoiding large variations in CVMC through precision irrigation can improve the consistency of fruit quality. Managing the accumulation of ions in the coir and improving plant tolerance to rising pore E.C values will also help to reduce the need for irrigation flushing events, and the subsequent negative impacts on fruit firmness, flavour, and shelf-life potential. A partial cost/benefit analysis will be conducted in Year 3 in which the investment and returns associated with deploying the irrigation treatments and manipulating the form of N nutrition will be compared.

Action points for growers

- Use substrate moisture and E.C. sensors to help manage coir pore E.C.
- For “Sonata” and Vibrant” 60-day crops, flushing events can be triggered at coir pore E.C. values of 3 – 3.5 mS cm^{-1} without reducing marketable yields or fruit quality.
- More precise management of coir pore E.C. will help to deliver on-farm improvements in water and fertiliser use efficiencies, and demonstrate compliance with new and impending legislation.
- Adjustment of manganese inputs is needed to avoid foliar toxicity at coir pore E.C values above 3.5 mS cm^{-1}.

SCIENCE SECTION

Introduction

The UK strawberry industry is a vital part of the UK's rural economy. The strawberry market continues to grow at a rate of 2.1% by volume per annum which is estimated at 106,606 tonnes, worth c. £454 million. The UK portion of the market was worth £244 million in 2014. Irrigation and the addition of fertilisers (fertigation) is essential to produce the high yields and berry quality expected by growers, retailers and consumers. Modern intensive substrate production systems incur high initial financial investments and require careful management to ensure quality is predictable, consistent and controllable. Nevertheless, the consistency of supply of high quality berries does vary between growers and between successive harvests and 32,000 tonnes of fruit picked each year is unmarketable due to small size, skin crazing and unacceptably soft fruit which is predisposed to bruising, rots and diseases. More precise management of water and fertiliser inputs could be expected to reduce fruit waste by at least 30%.

Growers are advised to irrigate to achieve 10-25% run-off to prevent the accumulation of damaging cations and anions within the substrate. However, HDC-funded research conducted at EMR (SF 107) and on commercial grower sites (SF 136) has shown that run-off can be eliminated without affecting Class I yields and aspects of fruit quality improved. Despite acknowledging that over-irrigation and high fertiliser inputs can lead to excessive vegetative growth, increased disease susceptibility, lower marketable yields, poor organoleptic quality and a short shelf-life, many growers are reluctant to reduce water (and fertiliser) inputs due to the lack of suitable management tools and crop monitoring systems. To help scale-up the low-input regimes developed by EMR to many hectares of high value commercial substrate strawberry production, innovative technological tools are being developed in a two Innovate UK-funded collaborative projects led by BerryGardens Growers Ltd in collaboration with EMR and other industry partners. In the meantime, new scientifically-derived grower guidelines for the precision production of substrate-grown “Sonata” and “Vibrant” need to be developed.

Despite the obvious benefits of our research, concern over perceived problems associated with increased substrate pore E.C. is limiting growers’ uptake of the new water- and fertiliser-saving techniques developed at EMR. To help growers gain confidence in reducing water and fertiliser inputs, the critical coir E.C. values that limit fruit size and quality in modern cvs such as “Sonata” and “Vibrant” need to be determined. Anecdotal evidence suggests that “Vibrant” is able to tolerate very dry substrates and since the physiological and metabolic adaptations elicited by limited water availability and salinity are similar, “Vibrant” may also be more tolerant of high substrate E.C. values. This possibility has yet to be tested.

There is an opportunity to improve tolerance to high substrate EC by manipulating ammonium-N ($N\text{-}NH_4$) and nitrate-N ($N\text{-}NO_3$) ratios (*e.g.* Ghanem *et al.,* 2011). This approach can also improve fruit number (Cardenas-Navarro *et al*., 2006), berry firmness, soluble solids content and shelf-life potential (Tabatabaei *et al.,* 2006, 2008). Manipulating the ratio of $N\text{-}NO_3$ to $N\text{-}NH_4$ would be of particular benefit in cvs such as “Sonata” where berries can be soft and vulnerable to bruising. Despite positive reports in the scientific literature, the UK soft fruit industry is wary of using ammonium nitrate as a major source of N. Currently, ammonium nitrate is used to provide $N\text{-}NH_4$ during fruit development, but is usually eliminated two weeks before picking as it can lead to unacceptable softening and subsequent poor shelf-life. Fruit albinism may also be induced with ammonium nitrate if silicon concentrations in irrigation water or substrate are high (Sharma *et al*., 2006). High ratios of $N\text{-}NH_4$ to $N\text{-}NO_3$ can limit photosynthesis and fruit quality as well as reducing calcium uptake and the supply of potassium and calcium must be managed carefully to optimise berry flavour and firmness (Ghanem *et al*., 2011). Strategic research is needed to test whether altering N nutrition in this way has the potential to improve both tolerance to high concentrations of ‘ions in the substrate (high E.C.) and yields and quality.

In previous work with ‘Elsanta’ at EMR (SF 107), changing the percentage of $N\text{-}NH_4$ from 10% to either 20% or 30% did not significantly affect plant physiology or fruit quality. In published work, higher ratios of $N\text{-}NO_3$ to $N\text{-}NH_4$ were needed to elicit physiological responses (*e.g.* 50%:50%, 25%:75%) but during the preparation of the SF107 proposal, strawberry industry representatives felt that $N\text{-}NO_3$ to $N\text{-}NH_4$ ratios greater than 70%:30% would limit fruit yields and quality. This was not the case. Work in other cropping systems has shown that a 70%:30% $N\text{-}NO_3\text{:}N\text{-}NH_4$ ratio did not affect physiology under normal conditions but improved shoot and root biomass and maintained leaf PSII efficiency under high salinity stress *via* altered plant hormone signalling (Ghanem *et al.,* 2011). More work is needed to determine the potential of manipulating N nutrition in this way to improve not only aspects of strawberry fruit quality and flavour, but also tolerance to high salinities and the build-up of ‘ballast’ ions in substrates. The outputs from SF 152 will also help to address the impact of poor quality irrigation water (high background EC) and increasingly saline irrigation water (due to salt water ingression) on soft fruit production.

More efficient use of inputs including labour, water and fertilisers is vital to the future success of the industry. The removal of the exemption for trickle irrigators, the on-going Abstraction Licence Reform and the UK’s recent failure to meet the objectives set out in the

Water Framework Directive around achieving 'good quality status' of our water bodies mean that on-farm water and fertiliser use efficiencies must be improved. Substrate growing is a major capital investment and yet irrigation/fertigation decisions are not often based on scientific evidence. The outputs from this project will improve the economic and environmental sustainability of UK soft fruit production by delivering greater water, fertiliser and pesticide use efficiencies, improved plant health, higher marketable yields, better fruit quality and a reduction in waste.

Materials and methods

Plant material

Bare-rooted grade A+ plants of "Vibrant" and grade A plants of "Sonata" and were obtained from Berry Plants at the end of January 2016 and stored at -2°C until needed. On 3 February 2016, plants were removed from the cold store and graded to improve size uniformity. Two crowns were planted in 3 L pots containing Botanicoir™; there were 60 pots for each cultivar (cv). Plants were placed in the GroDome (a controlled environment facility at NIAB EMR) at day/night temperature of 23 °C/17 °C with a 12 h photoperiod and 60% relative humidity (Figure 1 in Grower Summary). Daily relative humidity and temperature were monitored throughout the experiment (Figure 3). Throughout the experiment, all plants received the standard NIAB EMR pest and disease spray programme.

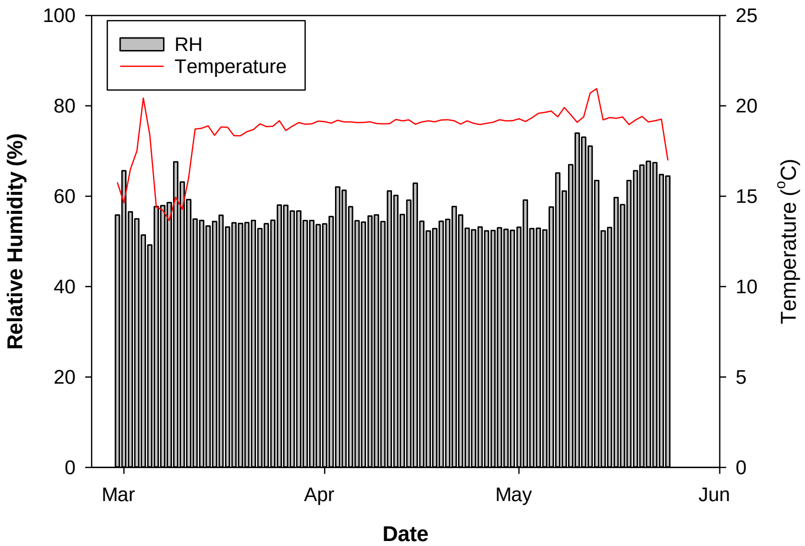

Figure 3. Average daily relative humidity and temperature in the GroDome at NIAB EMR.

Experimental Design

Two experiments were conducted simultaneously during 2016, one for each cv., to identify the pore E.C. values at which growth and cropping were negatively affected. Three E.C. treatments were applied: (i) EC2.5 where coir E.C. was kept below 2.5 mS cm^{-1}; (ii) EC3.5 where the coir E.C. was gradually raised to 3.5 and maintained between 3.5 and 4.0 mS cm^{-1}; (iii) EC4.5 where the coir E.C. was gradually raised to 4.5 and maintained between 4.5 and 5.0 mS cm^{-1}. The build up of coir E.C. throughout the experiment is presented in (Figure 1 – Grower's summary) Both experiments were set up as a complete randomised block design with twenty replicates. Experimental treatments started on the 29 February 2016, after plants have been established.

To control the build-up of coir pore E.C. in the different treatments, two feed solutions were applied, a commercial standard feed in which E.C. was maintained between 1.6 - 1.8 mS cm^{-1}, and a high E.C. feed in which E.C. was adjusted between 2.8 - 4 mS cm^{-1} to achieve the desired coir pore E.C. value. During plant establishment, the standard commercial feed was applied to all plants. The EC3.5 and EC4.5 treatments were then imposed on some plants by increasing the E.C. of the feed solution first to 2.8 mS cm^{-1}, then by gradually raising the feed E.C to 4.0 mS cm^{-1} to increase the rate of E.C. build-up during cropping. Once the target coir pore E.C. value was reached, the standard commercial feed was applied to maintain the coir pore E.C. within the desired ranges. The standard commercial feed composition was: 170 ppm N-NO_3,6 ppm N-NH_4, 35.9 ppm P, 254.9 ppm K, 131.1 ppm Ca, 36.0 ppm Mg, 1.44 ppm Fe, 0.16 ppm B, 0.06 ppm Cu, 0.45 ppm Zn, 1.11 ppm Mn, 0.06 ppm Mo.

Irrigation application and scheduling

The timing and duration of irrigation events were controlled using a Galcon DC-4S unit (supplied by City Irrigation Ltd, Bromley, UK) connected to manifold housing six DC-4S ¾" valves. Water was sourced from the mains (E.C. ~0.4 mS cm^{-1}) to ensure a reliable supply throughout the experiment. Irrigation water was delivered to each pot via a dripper stake connected to a 1.2 L $hour^{-1}$, non-return, dripper. Dripper outputs were tested prior to the experiment to ensure an accuracy of within 5%.

Figure 3. Decagon ECRN-50 rain gauges were used to measure volumes of run-off. Photo taken on 12 April 2016.

Coir volumetric moisture content, pore E.C. and run-off

Coir volumetric moisture content (CVMC) was monitored using Delta-T SM150 probes (Delta-T Devices Ltd). In each treatment, three sensors were connected to a Delta-T GP2 Advanced Datalogger and Controller unit. The average value from the SM150 probes was calculated automatically and if the average CVMC value was equal to or less than the irrigation set point, the solenoid valves were opened. The duration of irrigation at each event was adjusted to deliver run-off volumes <10% of input. Twice per week, 'spot' measurements of CVMC and coir pore E.C. in each pot were made with a Delta-T 'WET' sensor and a hand-held HH2 unit (Delta-T Devices Ltd) calibrated for coir. Two sets of holes were drilled into the side of the pots, one on the north side and one on the south side. The holes were positioned in the middle of the pot; this allowed for the horizontal insertion of the 'WET' sensor and provided a detailed profile of CVMC, pore E.C. and coir temperature throughout the rooting zone. Three plants per treatment were used to measure volumes of run-off. These pots were raised by placing them onto an upturned tray; the pots were tilted forward with the aid of wooden batons. The pots were previously placed in saucers which had a hole at the front edge; this hole was positioned directly above a Decagon ECRN-50 rain gauge (Decagon Devices Ltd, USA) which captured and measured the volume of run-off (Figure 3). The loggers were downloaded daily to calculate the % run-off volumes.

Measurement of physiological parameters

Measurements were made in each treatment in each experimental block twice per week.

Stomatal conductance (*g*s) and rates of photosynthesis (Pn) of fully expanded leaves were measured using a portable infra-red gas analyser (LI-6400 XT, LiCor Biosciences). Midday stem water potential of a young, fully expanded leaf from one plant per treatment in each experimental block was determined using a Skye SKPM 1400 pressure bomb (Skye Instruments Ltd, UK); leaves were covered carefully with aluminium foil for 90 min prior to measurement. One fruit and one leaf from each plant per treatment was labelled in each experimental block. Fruit expansion rates were estimated by measuring the width of one fruit at two diametrically opposed positions on the fruit shoulder, and the length, using digital callipers. Fruit volume was estimated from these measurements by assuming that the fruit were conical. Measurements were made from fruit set to harvest, and then new fruit were labelled and measured. Leaf extension was determined by measuring the length of the middle trifoliate leaf blade of young expanding leaves twice-weekly until maturity; new expanding leaves were then labelled and measured. In total, leaf extension of two expanding leaves was measured throughout the season.

Fruit yield and quality

Flowers were hand pollinated with a small artist's brush. Ripe fruit was harvested twice weekly. Fruit was graded, counted, and weighed for Class I, II and waste for each experimental plot.

Berry soluble solids content (SSC or %BRIX) was measured using a digital refractometer (Palett 100, Atago & co. Ltd, Tokyo, Japan) in juice collected by bulking Class I fruit from three experimental blocks. Fruit firmness (maximum load at 8 mm) of a bulk sample of Class I fruit from was determined with a penetrometer (Lloyds LRX TA plus).

Nutrient analysis

Mineral analysis was performed by a commercial analytical laboratory. Leaf and coir samples were analysed for N, P, K, S, Ca, Mg, Mn, Fe, Zn, Cu, B, and Mo at the end of the experiment. The leaf and coir samples were air dried, then dried in oven at 80 °C to a constant weight for estimation of dry matter accumulation . A subample was powdered then ashed in a furnace at 500 °C for nutrient analysis. For the the nutrients except N the ash was digested with concentrated hydrochloric acid and analysed by inductively-coupled plasma analyser (ICP). The determination of total organic N was carried out by the DUMAS combustion method. Sodium and Chloride were not included in the analyses.

Statistical analyses

Statistical analyses were carried out using Genstat 13.1 Edition (VSN International Ltd). To determine whether differences between irrigation treatments were statistically significant, analysis of variance (AVOVA) tests were carried out and least significant difference (LSD) values for $p<0.5$ were calculated.

Results

Coir volumetric moisture contents and coir pore E.C.

In both “Vibrant” and “Sonata”, the average CVMC in the treatments was maintained between 48% and 65% throughout the experiment.

In the EC2.5 treatment, coir pore E.C. was maintained below 3.5 mS cm^{-1} throughout development and cropping in both cvs. In “Vibrant”, the coir pore E.C. in the EC3.5 treatment reached the target value on 20 April 2016, and coir pore E.C. was generally maintained between 3.0 and 3.5 mS cm^{-1} throughout cropping. In the EC4.5 treatment, the highest coir pore E.C. value that could be achieved was 3.9 mS cm^{-1} on 4 May 2016.

In “Sonata”, the coir pore E.C. in the EC3.5 treatment reached the target value on 13 April

2016, and was maintained between 3.5 to 4.0 mS cm^{-1} until measurements made on 3 May 2016 indicated that the coir pore E.C. had risen to 4.5. Pots were then flushed with the commercial feed solution to reduce coir pore E.C.; values fell temporarily to 2.5 mS cm^{-1} and returned to target values by 13 May 2016. In the EC4.5 treatment, the coir pore E.C. reached the target value on 27 April 2016 and was maintained between 4.0 and 5.0 mS cm^{-1} for the remainder of the experiment.

Coir nutrient content

In “Sonata”, coir potassium (K) and phosphorus (P) concentrations were significantly higher under the EC4.5 treatment followed by the EC3.5 and then EC2.5 treatments (Table 2). Nitrogen (N), calcium (Ca), magnesium (Mg), boron (B) and zinc (Zn) accumulated in coir under the EC3.5 and EC4.5 treatments (Table 2) compared to the EC2.5 treatment. Manganese (Mn) coir concentrations was significantly higher under the EC4.5 treatment. There were no significant differences in coir sulphur (S), copper (Cu), molybdenum (Mo) and iron (Fe) concentrations between the treatments.

In “Vibrant”, coir N, K, P, Ca, Mg, Mn, Cu and Zn concentrations at the end of the growing season were significantly higher under the EC4.5 treatment (Table 2). Similar to “Sonata” S, Mo and Fe were not affected by the E.C. treatments. Boron coir concentration did not differ between the EC3.5 and EC4.5 treatments. Mn coir concentration was again higher in the EC4.5 treatment compared EC3.5 and EC2.5 treatments.

Table 2. Impact of E.C. treatments on macro- and micro-nutrient content on coir.

Treatment	N	K	P	Ca	Mg	S		Mn	B	Cu	Mo	Fe	Zn
	%							ppm					
Sonata													
EC2.5	1.3b	1.0c	0.1c	1.4b	0.3b	0.4a		70.6b	24.4b	9.5ba	1.5a	1588.4a	41.9b
EC3.5	1.8a	1.8b	0.2b	1.6a	0.4a	0.4a		85.3b	27.1a	42.8a	1.2a	1396.8a	55.9 a
EC4.5	1.9a	1.9a	0.3a	1.7a	0.4a	0.4a		121.6a	29.0a	26.9a	2.6a	1460.5a	63.4a
Vibrant													
EC2.5	1.3c	1.2c	0.1c	1.3c	0.3c	0.4a		84.3b	21.3b	11.3c	1.4a	1434.6a	46.3c
EC3.5	2.1b	2.3b	0.3b	1.7b	0.5b	0.4a		88.5b	27.3a	12.5b	1.2a	1524.8a	61.0b
EC4.5	2.6a	3.0a	0.4a	2.1a	0.6a	0.4a		133.9a	30.5a	15.5a	1.6a	1335.6a	75.2a

*means followed by the same letter are not significantly different (p=0.05)

Plant physiological responses to irrigation treatments

The effects of high pore E.C. on physiological plant responses to the E.C. treatments are shown in Figure 4.

In both cvs., the first statistically significant reductions in midday stem water potential were detected on 22 March 2016 when coir pore E.C. reached 2.5 mS cm^{-1} in the two high E.C. treatments, at that point coir pore E.C. in the EC2.5 treatment was 2.0 mS cm^{-1}(Figure 4C,F). From the Mid to end April, as the coir pore E.C. increased, values of midday stem water potential continued to diverege from control values in both cvs.

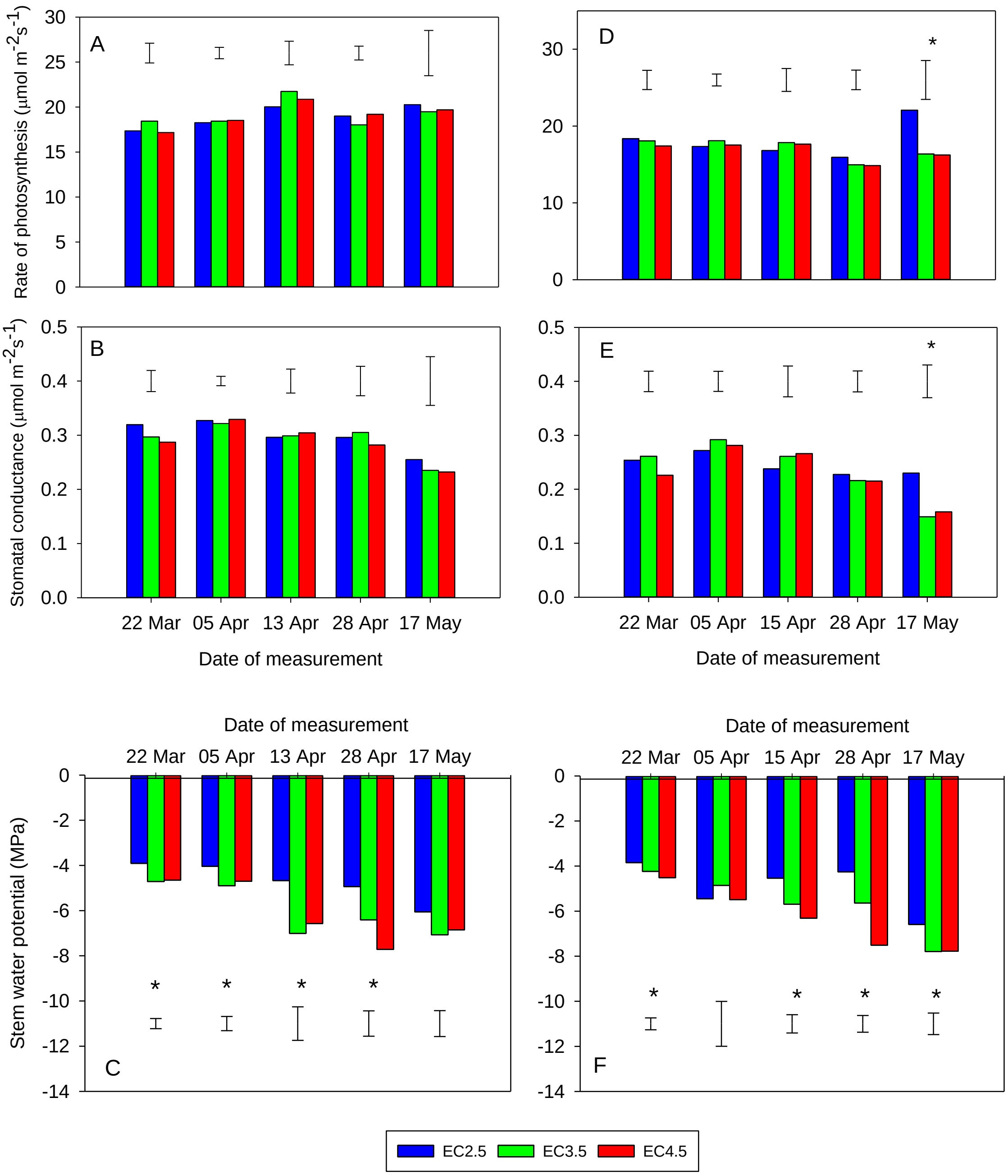

Figure 4. The effects of the three E.C. treatments on mean values of photosynthesis, stomatal conductance and midday stem water potential of "Sonata" (A,C,E) and "Vibrant" (D,E,F). Asterisks show significant differences between the treatments on the date of the measurement. Values are means of 12replicates, vertical bars represent LSD values (*p*<0.05).

In "Sonata", rates of photosynthesis and stomatal conductance were unaffected by the E.C. treatments, even when coir pore E.C. reached 2.0 mS cm^{-1}(Figure 4A,B). In contrast, in "Vibrant" rates of photosynthesis and stomatal conductance were reduced in the EC3.5 and EC4.5 treatments when the plants had been exposed to coir E.C. of 3.5 mS $cm^{-1}$for at least a month (Figure 4D,E). Fruit and leaf extension rates were not affected by the E.C. treatments in any of the cvs.

Leaf fresh and dry weight

High core pore E.C. caused a significant reduction in the rate of plant dry matter accumulation in both cvs (Figures 5 and 6). Dry matter accumulation in “Viibrant” was reduced by 22% and 49% under the EC3.5 and EC4.5 treatments, respectively, compared to control values. In “Sonata”, dry matter was reduced by 13% and 23% in the EC3.5 and EC4.5 treatments, respectively, compared to those in the EC2.5 treatment.

Figure 5. Effects of the three E.C. treatments on “Sonata” (A) and “Vibrant” (B) plant growth. From left to right EC2.5, EC3.5 and EC4.5 treatments; photo taken on 20 May 2016 at the end of the experiment.

Effect of E.C. treatments on shoot chemical composition

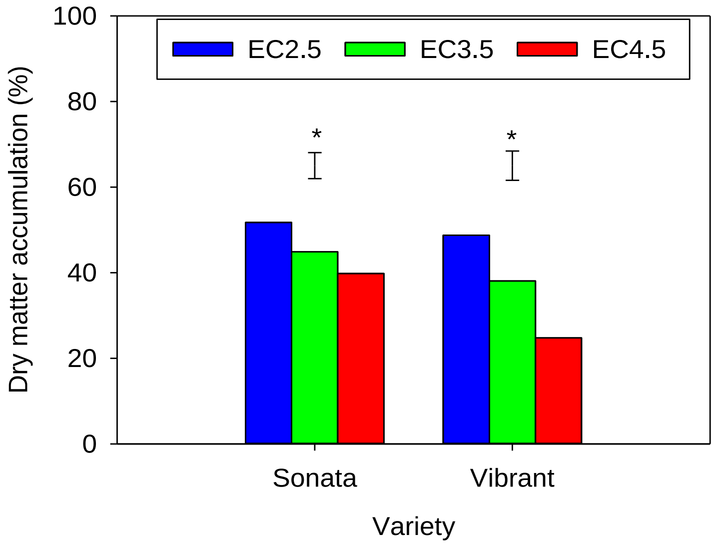

Figure 6. Effects of the three E.C. treatments on "Sonata" and "Vibrant" dry matter accumulation. Asterisks show significant differences between the treatments Vertical bars represent LSD values (p<0.05)

E.C. levels higher than 3.0 mS cm^{-1} (EC4.5) significant increased K and Mg concentrations in "Sonata" shoots. Coir pore E.C. values higher than 3.0 mS cm^{-1} increased S, Mn, B, Cu, Zn concentration in leaves. While, N, P, Ca, Mo, Fe shoot concentrations were unaffected by the E.C. treatments (Table 3).

Results presented in Table 3 reveal that N, K, S, Mn, B and Zn concentration in "Vibrant" shoots were raised unde the EC3.5 and EC4.5 treatments. In contrast, P, Ca, Mg, Mo and Fe shoot concentrations were unaffected by the E.C. treatments. Foliar concentrations of Cu were higher under the EC4.5 treatment.

Table 3. Impact of E.C. treatments on macro- and micro-nutrient contents of strawberry shoots.

Treatment	N	K	P	Ca	Mg	S		Mn	B	Cu	Mo	Fe	Zn
	%							ppm					
Sonata													
EC2.5	2.6a	3.1b	0.5a	1.3a	0.3b	0.2b		85.4b	72.8b	5.9b	0.2a	147.8a	30.3b
EC3.5	2.6a	3.3b	0.4a	1.3a	0.3b	0.2ab		384.2a	99.3a	7.3a	0.2a	200.4a	38.8a
EC4.5	2.8a	3.8a	0.4a	1.3a	0.3a	0.2a		387.5a	90.6a	7.3a	0.3a	196.6a	38.8a
Vibrant													
EC2.5	2.5c	3.2c	0.5a	1.7a	0.4a	0.2c		97.0c	62.0c	5.9b	0.2a	240.2a	40.2b
EC3.5	2.9b	3.9b	0.5a	1.7a	0.4a	0.2b		527.3b	73.6b	6.4b	0.2a	308.0a	41.5ab
EC4.5	3.4a	4.8a	0.5a	1.9a	0.5a	0.2a		667.0a	82.9a	7.0a	0.3a	315.8a	46.6a

*means followed by the same letter are not significantly different (p=0.05)

Effects of E.C. treatment on fruit yields and quality

Total yields (Class I and II) fruit were around 587 g per pot and 325 g per plant for “Sonata” and “Vibrant”, respectively (data not shown) when grown under optimal E.C. levels but statistically decreased by 15% and 38%, respectively when grown under the EC4.5 treatment. Average yields of Class I fruit per plant were lowered as E.C. levels increased in both cvs. (Table 1 – Grower Summary). Class I size berries were decreased by *c.* 10% in both cvs. In “Vibrant” the total number of fruits was lower in the EC4.5 treatment (Figure 7), due to treatment effects of plant growth, fruit set and expansion.

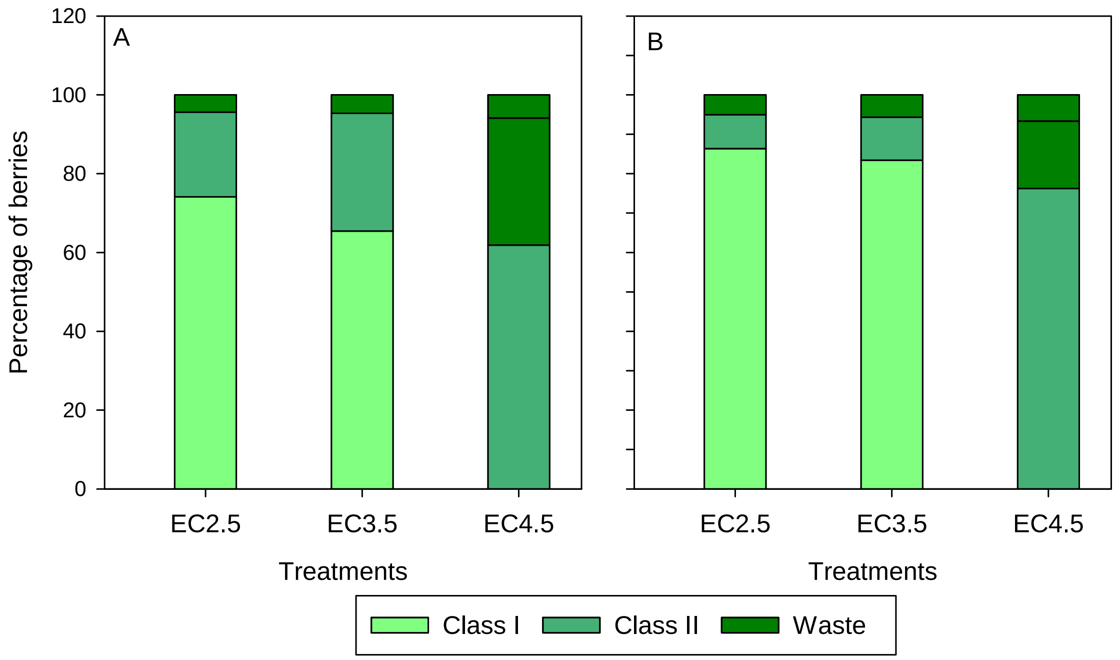

Figure 7. Effects of E.C. treatments on “Sonata” (A) and “Vibrant” (B) marketable yields and waste.

There were no significant treatment effects on fruit firmness or soluble solids content (%BRIX) in either cv. (Table 1 – Grower Summary) at any of the measurement dates, therefore average values of firmness and BRIX are presented.

Discussion

Substrate strawberry production is a major capital investment and yet irrigation/fertigation decisions are not often based on scientific evidence. An over-supply of water and fertilisers can limit fruit quality and shelf-life, and these detrimental effects are often accentuated in changeable weather. Producing a consistent supply of high quality, phytonutritious berries with an assured shelf-life is challenging and currently, an estimated 33% of all harvested fruit is wasted each year, due to disorders such as rots, bruising and a poor shelf-life. This project aims to deliver precision irrigation/fertigation management during substrate production of “Sonata” and “Vibrant”.

Strawberry cvs differ in their responses to NaCl salinity (Keutgen et al., 2009) and the salt-stress adaptation in plants is complex and is influenced by many interacting environmental factors. Our results suggest that “Vibrant” was more sensitive to high coir pore E.C. levels as plants in the EC4.5 treatments developed large necrotic areas on the leaves due to Mn toxicity; these symptoms were also present in plants under the EC3.5 treatement but to a lesser degree. The effects o the high EC treatments on plant growth and fruit yield were more pronounced in “Vibrant” than in “Sonata.

In all treatments and in both cvs, leaf nutrient concentrations were within recommended levels for strawberries, with the exception of K and Mn. Elevated N concentrations under salinity are thought to contribute to the syntheses of specific N compounds such as amino acids (e.g. proline and aspartic acids), amides (glutamine and asparagine) and the stress-related proteins (Mansour, 2000).

The solubility of micronutrients such as Fe, Mn and Zn can be reduced by NaCl salinity (Alam, 1999), but their uptake can be enhanced under salt stress (Alam, 1999). In our experiments, Fe and Mo concentrations were not significantly affected, while B, Cu, Mn and Zn increased in shoots (Table 6). In agreement with our findings, Turhan (2005), reported increased Mn leaves concentrations in “Camarosa” and “Tioga” grown under saline conditions. Manganese toxicity symptoms appeared as necrotic spots along the margins of leaves; these spots enlarged greatly within a few days and ultimately the leaves shrivelled.

“Sonata” and “Vibrant” plants plants grown under optimal coir pore E.C. produced larger fruit than those under the EC3.5 and EC4.5 treatments. . Fruit size reduction under a saline environment is attributed to the inhibition of water uptake and reduced water transport to the fruit (Alam, 1999). In berries, K improves turgor maintenance but may reduce fruit size when recommended concentrations are exceeded (Albregts et al., 1996). In the present experiment, K concentrations in leaves of "Sonata" increased by 23% while in the more sensitive "Vibrant" K concentrations increased by 50%. This response is likely to be species specific since Alam (1999) reported that, in several plants, K accumulation is limited under salinity.

Manipulating ratios of $N\text{-}NH_4$ to $N\text{-}NO_3$ have been reported to improve plant tolerance to salinity (Tabatabaei et al., 2006). On the last year of the Project, three different ratios of $N\text{-}NH_4$ to $N\text{-}NO_3$ (1:9, 3:7 and 5:5) will be tested on high coir EC3.5 treatments to evaluate the potential to use targeted fertigation to ameliorate the negative effects of high coir E.C. values.

Conclusions

- The coir pore E.C. values that limit important agronomic traits in "Sonata" and "Vibrant" were identified
- Transient rises in coir pore E.C. to 3.5 mS cm^{-1} did not affect marketable yields and fruit quality
- Class I yields of "Sonata" and "Vibrant" were reduced when coir pore E.C. was raised above 4.0 mS cm^{-1}, but berry quality was unaffected
- "Vibrant" appears to be more sensitive than "Sonata" to high coir pore E.C. levels
- Manganese toxicity was observed under the EC3.5 and EC4.5 treatments
- Potassium accumulation at high coir pore E.C. values may limit fruit expansion and lead to lower Class 1 yields
- Nutrient formulations need to be refined for each cv to avoid toxicity, foliar dessication and yield reduction at higher coir pore E.C. levels

Knowledge and Technology Transfer

- Presentation of the project aims and objectives at the Institute of Agricultural Engineers' Annual Conference (May 2015)
- Presentation of the project aims and objectives at the AAB Knowledge Exchange Conference 20 June 2015, Lancaster University

- Project aims and objectives were discussed during the WATERR Workshop to tree fruit growers at Fruit Focus, 23 July 2015, EMR
- Project aims and objectives were presented at the WATERR Project Closing Workshop, 28 September 2015, EMR
- Project aims, objectives and results were presented at the Delta-T “SPAC” conference, 13 October 2015, Rothamsted Research, Harpenden
- Project aims, objectives and results were presented in a article published in the AHDB Soft Fruit review magazine, February 2016
- Project aims, objectives and results were presented in a article presented in the AHDB Horticulture Soft Fruit agronomist day, February 2016

References

Albregts, E. E., Hochnmth, G. J., Chandler, C. K., Cornell, J., & Harrison, J. (1996). Potassium fertigation requirements of drip-irrigated strawberry. Journal of the American Society for Horticultural Science 121(1):164-168

Alam, S. M. (1999). Nutrient uptake by plants under stress conditions. Handbook of plant and crop stress 2:285-313

Cardenas-Navarro R., Lopez-Perez L., Lobit P., Ruiz-Corro R. & Castellanoos-Morales V.C. (2006). Effects of nitrogen source on growth and development of strawberry plants. Journal of Plant Nutrition 29:1699-1707

Cocco, C., Andriolo, J.L., Cardosa, F.L., Erpen, L. & Schmitt, O.J. (2011). Crown size and transplant type on the strawberry yield. Scientia Agricola 68:489-493

Ghanem M.E., Martinez-Andujar C., Albacete A., Pospisilova H., Dodd I.C., Perez-Alfocea F. & Lutts, S. (2011). Nitrogen form alters hormonal balance in salt-treated tomato (*Solanum lycopersicum* L.). Journal of Plant Growth Regulation 30:144-157

Mansour, M. M. F. (2000). Nitrogen containing compounds and adaptation of plants to salinity stress. Biologia Plantarum 43(4):491-500

Tabatabaei S.J., Faterni L.S. & Fallahi E. (2006). Effect of ammonium:nitrate ratio on yield, calcium concentration and photosynthesis rate in strawberry. Journal of Plant Nutrition 29:1273-1285

Tabatabaei S.J., Yusefi M. & Hajiloo, J, (2008). Effects of shading and NH3:NH4 ratio on the yield, quality and N metabolism in strawberry. Scientia Horticulturae 116:264-272

Turhan, E., & Eris, A. (2005). Changes of Micronutrients, Dry Weight, and Chlorophyll Contents in Strawberry Plants Under Salt Stress Conditions.Communications in Soil Science and Plant Analysis 36(7-8):1021-1028

