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
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Key staff:	Mike Davies, Clare Hopson, June Taylor, 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.

Dr Eleftheria Stavridou

Research Leader

NIAB EMR

Signature .. Date 31 March 2017

Report authorised by:

Signature: Date:

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GROWER SUMMARY

Headline

- Increasing the ratio of ammonium to nitrate nitrogen in substrate grown strawberry feeds can overcome the loss of yield caused by high E.C.

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 the 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 to achieve ‘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.) has discouraged grower 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 and nitrate ratios. This approach can improve fruit number, berry firmness, soluble solids content and shelf-life potential. Manipulating the ratio of ammonium:nitrate would be of particular benefit in cultivars like ‘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. Ammonium nitrate is currently used to provide ammonium 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 was tested in Year 3 of this project.

The project aims were:

- To improve consistency of fruit quality and reduce unmarketable/waste fruit in Sonata and Vibrant
- 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 to manipulate N nutrition to improve tolerance to high coir pore E.C.

Summary of the project and main conclusions

In the first two years of the project, experiments were done to establish the coir moisture content at which Sonata and Vibrant plants began to show the first signs of a drought response. The results were used as a basis for irrigation control setpoints in experiments to find out the EC values at which productivity and fruit quality begin to be affected.

In these experiments, three different EC treatments were imposed: in one, the coir EC was kept below 2.5mS/cm; in the second, EC was raised gradually to 3.5 and then maintained between 3.5 and 4.0mS/cm; and in the third, EC was raised gradually to 4.5 and then maintained between 4.5 and 5.0mS/cm.

In Sonata, photosynthesis and the degree of stomatal opening – used as an indication of a plant's stress response – were unaffected by being grown at the higher EC values. In contrast, photosynthesis and stomatal opening were significantly reduced in Vibrant after prolonged exposure to EC levels of 3.5mS/cm and higher, compared with plants where EC was kept below 2.5mS/cm.

For both varieties, however, neither marketable yields nor fruit quality were affected by short-term increases in EC to 3.5mS/cm. Class 1 yields fell when EC exceeded 4.0mS/cm, although berry quality was unaffected. Some manganese toxicity symptoms were seen in plants at both of the higher EC levels.

In the work's final year, the scientists investigated whether there is an opportunity to improve a crop's tolerance to high substrate EC by manipulating its source of nitrogen – varying the ammonium and nitrate ratios.

2016 experiments

Plants were established during August when they were given a commercial standard vegetative feed. Fertigation was switched to a fruiting feed at the end of August, and that was when the different experimental regimes were imposed.

There were four treatments:

1. The commercial standard, in which the coir EC was maintained at approximately 2.5mS/cm and nitrogen was applied in a 10:90 ratio – that is, 10% of the nitrogen was supplied as ammonium and 90% as nitrate
2. The same ammonium:nitrate ratio as the commercial standard but with the coir EC at the higher level of 3.5mS/cm
3. Coir EC at 3.5mS/cm but with a higher proportion of the nitrogen supplied as ammonium, at 50% ammonium and 50% nitrate
4. Coir EC at 3.5mS/cm but with the proportion of the nitrogen supplied as ammonium further increased, to 75% ammonium and 25% nitrate

The total amount of nitrogen applied was the same for each, only the contribution made by each nitrogen source was varied. All the key micronutrients were kept the same for each treatment, too. The high EC feeds were achieved by altering the concentrations of sodium, chlorine and sulphur – the water leaving the drippers in these treatments was maintained at 3.0 to 3.5mS/cm, enabling the coir EC to climb to the required level. For the commercial standard treatment the fertigation EC, at the drippers, was held at 1.6 to 1.8mS/cm, to limit the build-up of ions in the substrate. The pH of the irrigation water for each regime was kept at 5.8 to 6.2.

Both varieties showed measurable levels of water stress under the high EC regimes, irrespective of the proportion of ammonium in the nitrogen feed.

The Sonata plants grew less well in the high EC regimes, except where the highest ammonium ratio was used, when growth was comparable with plants under the commercial regime.

The situation was less clear for Vibrant. There was no significant difference in growth between the EC regimes, though at the high EC with ammonium and nitrate at equal rates, plants grew significantly better than in the other treatments. Plants in the trial were not as vigorous as Sonata and had been grown from smaller sized crowns.

Sonata yielded 206g of Class 1 fruit per plant under the standard EC regime. Raising the EC at the standard ammonium:nitrate ratio reduced this by about 20% to 167g, due to fewer Class 1 berries and more at Class 2. In the other high EC treatments, where more of the nitrogen was supplied as ammonium, yields were significantly better. Although there were 5% fewer Class 1 berries, this wasn't statistically significantly different from the standard regime.

Vibrant's yields were generally around half those of Sonata, a direct result of the smaller and less vigorous planting material in this particular trial. The variety produced 102g of Class 1 per plant in the standard commercial regime and, as in Sonata, raising the EC with no change to the ammonium:nitrate ratio significantly reduced yields, by a similar percentage, to 83g at Class 1 – again due to fewer and smaller berries. Both of the higher ammonium regimes largely overcame the EC effect so that Class 1 yields were similar to those under the commercial EC and nitrogen regime.

Fruit firmness didn't vary significantly for either variety between any of the treatments and it was notable that the higher ammonium ratios didn't lead to softer fruit.

Soluble solids content, or Brix, was significantly higher in fruit from both varieties from the high EC and standard nitrogen regime. For Sonata there were also significant differences between treatments in the concentration of malic acid, which was lower in fruit from all the high EC treatments, and total acids, which were reduced by the combination of high EC and high ammonium.

From the yield and quality results – and the tissue analyses which are detailed in the full project report – it looks as if increasing the ammonium rate leads to a better plant nutrient status at higher EC levels, which counteracts the otherwise damaging effects of salinity stress.

Financial benefits

Early work in this project demonstrated that water and fertiliser savings of 34% and 5% can be achieved for Sonata and Vibrant grown under precision 'closed loop' fertigation, where run-off is eliminated and coir kept near water holding capacity.

In the third year trial high E.C. reduced Class I yields by up to 18%. On a 10 ha farm yielding 25 t/ha, this would result in a loss of £157K p.a. However appropriate adjustment of ammonium:nitrate ratio can reduce the impact by 8-100%, eliminating the income loss.

Action points for growers

- A new irrigation scheduling tool has been developed using setpoints based on coir volumetric moisture contents. Combined with the use of substrate moisture and EC sensors, growers can employ it to make significant water and fertiliser savings.
- Water and fertiliser savings of 36% can be achieved for Sonata and 5% for Vibrant.
- Yields of both Sonata and Vibrant are significantly reduced when coir E.C. is maintained above 3.5 mS/cm during cropping.
- For 60-day crops of Sonata or Vibrant, flushing can be triggered at coir EC values of 3 to 3.5mS/cm with no adverse effect on marketable yields or fruit quality.
- In Sonata and Vibrant, increasing the ammonium:nitrate ratio to 50:50 and 75:25 can reduce the adverse impact of high EC above 3.5 mS/cm on yield.
- High ammonium application did not affect fruit firmness in this project.
- Higher ammonium application decreased coir pH.
- Nutrient formulations need to be refined for each cultivar to avoid toxicity, foliar desiccation and yield reduction at higher coir pore E.C. levels.

SCIENCE SECTION

Introduction

The UK strawberry industry is a vital part of the UK's rural economy and the market continues to grow. Strawberries were worth an estimated £284 million in 2015, up 16% on 2014 and production reached a new high of 115 thousand tonnes, up 11% on 2014 (DEFRA Horticultural Statistics 2016). 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 that is predisposed to bruising, rots and diseases. With more precise management of water and fertiliser inputs many of these facors could be mitigated, reulting in a reduce fruit waste of at least 30%.

For commercial production growers are strongly advised to irrigate to achieve 10-25% run-off to prevent the accumulation of damaging cations and anions within the substrate. However, research funded by AHDB Horticuture which was 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 can be 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 research outcomes from EMR, concern over perceived problems associated with increased substrate pore E.C. is limiting uptake of the new water- and fertiliser-saving techniques by growers. 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 cultivars 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 E.C. 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 E.C. by manipulating ammonium and nitrate ratios (Ghanem et al., 2011). This approach can also improve fruit number (Cárdenas-Navarro et al., 2006), berry firmness, soluble solids content and shelf-life potential (Tabatabaei et al., 2008; Tabatabaei et al., 2006). Manipulating the ratio of nitrate to ammonium 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 ammonium 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 ammonium:nitrate 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 ammonium from 10% to either 20% or 30% did not significantly affect plant physiology or fruit quality. In published work, higher ratios of nitrate to ammonium 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 nitrate:ammonium 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% nitrate:ammonium 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 E.C.) 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 1 August 2016, plants were removed from the cold store. As the Vibrant plants were smaller sized crowns than "Sonata", two crowns were planted per hole in 50cm Botanicoir™ bags; 16 plants per bag. One crown plants of "Sonata" were planted in 50cm Botanicoir™; 8 plants per bag; 32 bags for each cultivar (cv). Throughout the experiment, all plants received the standard NIAB EMR pest and disease spray programme.

Experimental Design

Two experiments were conducted simultaneously during 2016, one for each cv., to identify the effect of adjusting the ammonium:nitrate ratio in the fertigation system for plants experiencing high E.C. coir pore E.C. Four treatments were applied:

1. CC 10:90, the commercial control, where coir E.C. was maintained at approximately 2.5 mS cm^{-1} and nitrogen was applied in a ratio of 10:90, ammonium:nitrate (i.e. 90% of N came from nitrate, and 10% from ammonium);
2. HS 10:90, where bag coir E.C. was raised and maintained at E.C. 3.5 mS cm^{-1} with a ammonium:nitrate ratio as the CC
3. HS 50:50, E.C. raised to 3.5 mS cm^{-1} but with an ammonium:nitrate ratio of 50:50
4. HS 75:25, E.C. raised to 3.5 mS cm^{-1} but ammonium:nitrate ratio of 25:75.

Each of the four treatments had a separate three dosatron three feed tank system to apply the correct fertigation regime to each treatment. Each fertigation regime had a Tank A (containing calcium nitrate and other macronutrients), Tank B (containing micro and macro nutrients) and Tank C (acid to adjust irrigation pH independently to each line). All the major and important micronutrients were kept constant between irrigation regimes (P, K, Ca, Mg, Fe, B, Cu, Zn, Mn, Mo), and whilst the total amount of N applied to each treatment was the same the source of that N differed with the amount applied as ammonium-N and the amount applied as nitrate being adjusted to obtain the correct ratio differences. The high E.C. feeds were achieved by altering the concentrations of Na, Cl and S, the E.C. of the water leaving the drippers in these treatments was maintained at 3.0 - 3.5 mS cm^{-1}, so that coir E.C. could be built up to 3.5 mS cm^{-1}. The E.C. of the fertigation being applied to the CC was maintained 1.6 - 1.8 mS cm^{-1}, so that coir E.C. build up was limited. In each irrigation regime, the pH of the irrigation water was maintained at 5.8 – 6.2. Both experiments were set up as a complete randomised block design with eight replicates. The 50cm Botanicoir™ bags were placed on tabletops with an outer guard row on either side in a polytunnel at NIAB EMR.

During plant establishment, 1 August – 31 August, the standard vegetative commercial feed was applied to all plants. On 31 August, fruiting feed began to be applied, with the different fertigation regimes starting to be applied to each of the treatments.

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%. Irrigation was independently controlled to each treatment via a closed loop irrigation system. In each treatment coir volumetric moisture content (CVMC) was monitored using three Delta-T SM150 probes (Delta-T Devices Ltd), positioned centrally within different bags, and connected to a Delta-T GP2 Advanced Datalogger and Controller unit. The average value from the three 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.

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

Initially, August and early September, "spot" measurements of CVMC and coir pore E.C. were made twice per week; thereafter "spot" measurements were done five times per week. These "spot" measurements were made with a Delta-T "WET" sensor and a hand-held HH2 unit (Delta-T Devices Ltd) calibrated for coir, with readings taken from 3 positions within each experimental bag; one reading was made directly under a plant, another directly under a dripper and the third mid-way between the two, all readings were made mid-way between the top and bottom. Three bags per treatment were used to measure volumes of run-off, these bags had a plastic sheet suspended underneath them so as to capture any water filtering through the bags. This run-off was then channelled into an Decagon ECRN-50 rain gauge (Decagon Devices Ltd, USA) which captured and measured the volume of run-off.. The loggers were downloaded daily to calculate the % run-off volumes.

Measurement of physiological parameters

Measurements were made on 1 plant in each experimental bag weekly between 15 September and 25 October 2016.

Stomatal conductance and rates of photosynthesis 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 from each experimental bag was labelled. 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. In total, fruit expansion of two expanding fruit per bag was measured throughout the season.

Leaf nutrient analysis

Mineral analysis was performed by a commercial analytical laboratory. Leaf samples were analysed for nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), and boron (B) at the end of the experiment. The leaf samples were air dried, then dried in an oven at 80 °C and powdered. Samples were then ashed in a furnace at 500 °C. For 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.

Fruit yield and quality

A beehive was placed into the polytunnel prior to the first flower opening to ensure good pollination of the emerging strawberry flowers. Ripe fruit from each experimental bag was harvested twice weekly, from 12 September to 2 November 2016 for “Vibrant” and 15 September to 17 November for “Sonata”. All fruit was graded, weighed and Class I yields, small fruit and waste recorded. Each week two Class I fruit from each experimental bag were assessed for berry soluble solids content (SSC or %BRIX) was measured using a digital refractometer (Palett 100, Atago & co. Ltd, Tokyo, Japan). Fruit firmness (maximum load at 8 mm) of a bulk sample of Class I fruit from each treatment was determined with a penetrometer (Lloyds LRX TA plus). On 3 occasions, 3 October, 20 October and 27 October samples of three Class I fruit from each experimental plot of “Sonata” was collected for sugar, organic acid, and total anti-oxidant analysis. The fruit was chopped, sealed into labelled plastic bags and frozen immediately in liquid nitrogen, before storing at -80 °C until analysis.

Fruit chemical analysis

Sample preparation

Strawberry samples previously stored at -80 °C were freeze dried, then crushed to a fine power. Sub-samples of 200mg were used for sugar and organic acid analyses and 100mg used for measuring trolox equivalent antioxidant capacity (TEAC).

Sugars and acids

Samples were homogenised in 10ml of ultra-pure water containing 5mM Tris (2-carboxyethyl) phosphine hydrochloride, vortexed, then shaken for 30 min at 4 °C on an orbital shaker, and then centrifuged at 4800 g for 25 min. Two 500 µL aliquots of sample were pipetted into separate Thomson 0.45 µm PTFE filter vials, one for acid analysis the other for sugar analysis.

For the sugar analysis, 5 µL of sample were injected into a Waters Alliance 2690 HPLC. Sugars were separated on a Luna amino column 250 x 4.6 mm, 3 µm internal diameter (Phenomenex) and detected with a Waters 410 differential refractometer (RID). The mobile phase was 80:20 acetonitrile: ultra-pure water with a flow rate of 1.5 ml min^{-1}, column and RID temperature was 40 °C. Standards of known amounts of fructose, glucose and sucrose were injected into the HPLC and $Millinium^{32}$ software was used to produce linear calibration curves in the range of 5 to 50 µg with an r^2 0.999. These calibration curves were used to determine the concentration of fructose, glucose, and sucrose in the samples.

Organic acids

For the acid analysis, a 10µL injection of the sample was made into a Waters Alliance 2690 HPLC. Acids were separated on a Synergi hydro RP C18 250 x 4.6 mm, 5 µm internal diameter column (Phenomenex) and detected with a Waters 996 photodiode array (PDA) detector. Malic and citric acid were detected at 220 nm and ascorbic acid was detected at 243 nm. The mobile phase was 10 mM potassium phosphate pH 2.7 with a flow rate of 1 ml min^{-1} with column temperature at 20 °C. Standards of known amounts of malic, citric and ascorbic were injected into the HPLC. $Millinium^{32}$ software was used to produce linear calibration curves in the range of 1.5 to 10 µg for malic acid, 2.5 to 20 µg for citric acid and

0.25 to 2 µg for ascorbic acid, each with an r^2 value of 0.999. These calibration curves were used to determine the concentration of malic, ascorbic and citric in the sample.

Total antioxidant capacity

Hydrophilic anti-oxidants were extracted by homogenising the sample in 10ml of [80:20] [methanol: water], vortexed and then shaken for 30 min at 4 °C on an orbital shaker then centrifuged at 4800g for 20 min. The supernatant was decanted. To determine the anti-oxidant capacity of the samples the TEAC method was used.

7mM 2,2” –Azino-bis(3-ethyl benzothiazoline-6-sulfonic acid) diammonium salt (ABTS) in ultrapure water was converted to its mono-cationic form (ABTS+) by the addition of 2.45mM (final concentration) potassium persulphate ($K_2S_2O_8$), this solution was left in the dark at room temperature for 24hrs.

The ABTS+ solution was diluted [1:100] [ABTS+: ethanol] it was kept in the dark and the temperature maintained at 30 °C. A thirty micro-litre aliquot of the solvent extract was pipetted into a 3ml cuvette containing this ABTS+ solution.

The cuvettes were placed in a water bath at 30 °C for 15 min.

Measurements of absorbance were then made with a Pharmacia ultraspec III spectrophotometer at a wavelength of 734 nm.

The absorbance of the standards of 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) in the concentration range of 0 to 2mM were measured and the % inhibition of the ABTS+ was calculated and a linear graph, r^2 0.999 produced. This graph was used to determine the amount of anti-oxidant capacity in the samples relative to the reactivity of Trolox.

Plant growth responses

At the end of the trial, on 21 November 2016, the plants were destructively harvested to determine the fresh and dry weights of plants in each treatment. The leaves, petioles, and trusses of all the plants in each bag were removed, and the fresh weight recorded, the crown was then removed and fresh weight recorded separately. Both samples, a) leaves, petioles, trusses and b) crowns were then placed in an oven at 80 °C for 48 h and dry weights were recorded. The fresh weight:dry weight ratio was calculated.

Coir pH

At the end of the trial a sample of coir, was removed from across the depth of each experimental bag. The coir was then mixed at a ratio of 2.5 parts water to 1 part coir and placed on an automatic shaker for 15 minutes. The pH of the solution was then determined.

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”, CVMC, averaged across the three measurement points in each bag was maintained in each treatment between 50% and 67% throughout the experiment and therefore no treatment suffered any irrigation deficit (**Figure 1**).

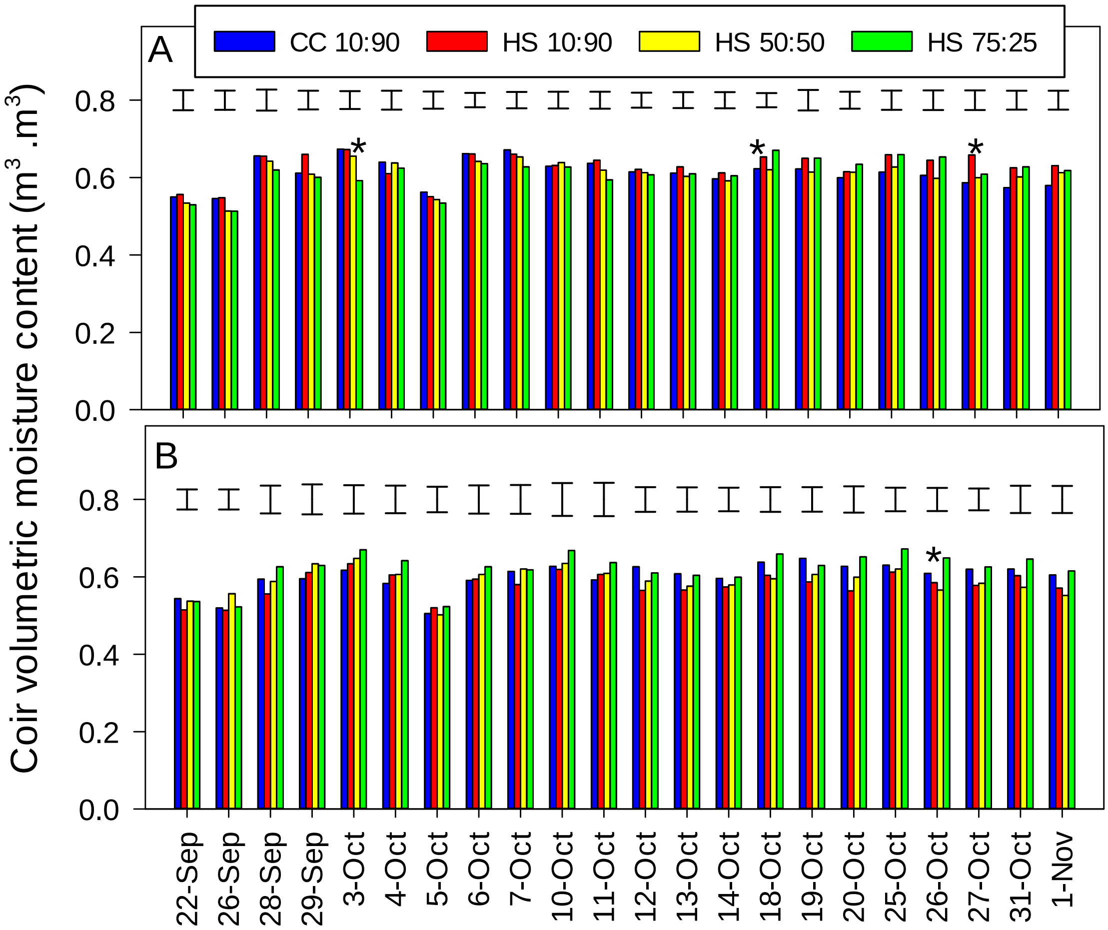

Figure 1. Average bag CVMC in A) "Sonata" and B) "Vibrant", from "spot" measurements made with a Delta-T "WET" sensor, averaged across 3 positions within a bag, directly under a plant, directly under a dripper and mid-way between the two. Asterisks (*) indicate significant differences between the treatments. Error bars represent LSD at 5%.

In "Sonata", coir pore E.C., averaged across the 3 measurement positions (directly under plant, under dripper and mid-way between the two) was successfully increased to 3.5 mS cm^{-1} in the high-E.C. treatments (Figure 2B), reaching the target value by the 28 September for HS 10:90 and HS 50:50 treatments and 3 October for HS 25:75. Thereafter E.C. in these three treatments was kept at or near this value for the remainder of the trial, with average E.C. (across all dates after reaching target E.C.) of 3.6 mS cm^{-1} for HS 10:90 and 3.4 mS cm^{-1} for HS 50:50 and HS 75:25. In the CC 90:10 treatment average coir pore E.C. was maintained below 3.0 mS cm^{-1} throughout the trial, averaging 2.6 mS cm^{-1} across the main cropping period (end September to mid-November). In all treatments, coir pore E.C. was higher when measured directly under the plant (Figure 2A), approximately 15% higher under the plant than when measured mid-way between plant and a dripper and 20% higher than when measured directly under the dripper. In "Sonata", the average coir pore E.C. measured directly under the plant, across the main cropping period was 2.9, 4.0, 3.7 and 3.8 mS cm^{-1} for CC 10:90, HS 10:90, HS 50:50 and HS 75:25 respectively.

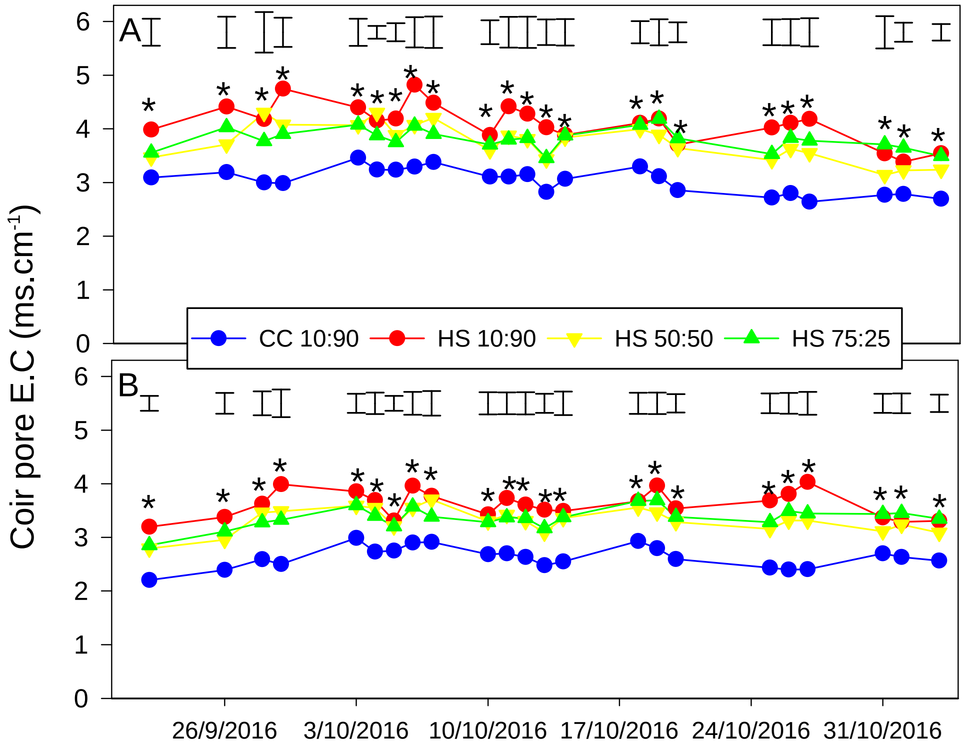

Figure 2. Average bag coir pore E.C. "Sonata" when measured A) directly underneath a plant and B) averaged from 3 positions (directly under a plant, directly under a dripper and mid-way between the two) from "spot" measurements made with a Delta-T "WET" sensor. Asterisks (*) indicate significant differences between the treatments. Error bars represent LSD at 5%.

In "Vibrant", coir pore E.C., averaged across the 3 measurement positions (directly under plant, under dripper and mid-way between the two) reached 3.5 mS cm^{-1} in the high E.C. treatments on 29 September (Figure 3B), thereafter E.C. in these three treatments fluctuated between 2.8 and 3.8 mS cm^{-1} for the remainder of the trial, with average E.C. (across all dates after reaching target E.C.) of 3.2 mS cm^{-1} for HS 10:90, and 3.0 mS cm^{-1} for HS 50:50 and 3.1 mS cm^{-1} for HS 75:25. In the CC 10:90 treatment average coir pore E.C. was maintained below 3.0 mS cm^{-1} throughout the trial, averaging 2.5 mS cm^{-1} across the main cropping period (end September to mid-November). As in "Sonata" coir pore E.C. was higher when measured directly under the plant. In "Vibrant", the average coir pore E.C. measured directly under the plant across the main cropping period was 2.8, 3.2, 3.4 and 3.5 mS cm^{-1} for CC 10:90, HS 10:90, HS 50:50 and HS 75:25 respectively.

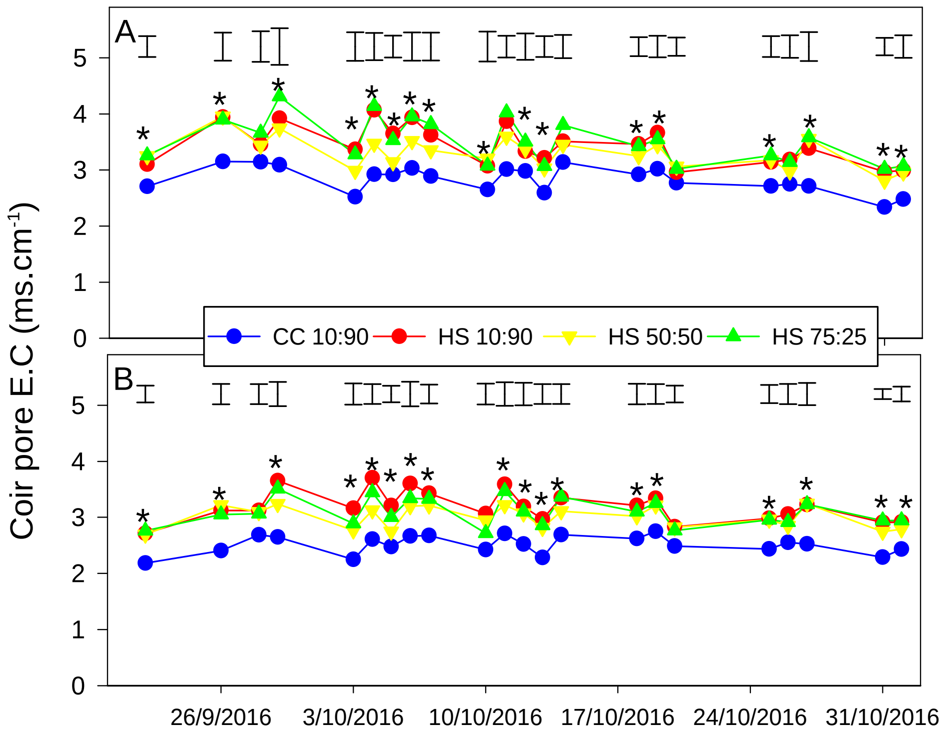

Figure 3. Average bag coir pore E.C. "Vibrant" when measured A) directly underneath a plant and B) averaged from 3 positions (directly under a plant, directly under a dripper and mid-way between the two) from "spot" measurements made with a Delta-T "WET" sensor. Asterisks (*) indicate significant differences between the treatments. Error bars represent LSD at 5%.

Coir pH

In both "Vibrant" and "Sonata" coir pH at the end of the trial was significantly lower in those bags that received the higher ammonium ratios, HS 50:50 and HS 75:25, than the bags receiving the 10:90 ammonium:nitrate regimes (Table 1). The difference was approximately 1 pH unit, there being no significant difference between the two treatments receiving the higher ammonium.

Table 1. The effects of the four fertigation regimes on coir pH at the end of the trial for "Sonata" and "Vibrant".

	"Sonata"	"Vibrant"
CC 10:90	5.8^{b}	5.8^{b}
HS 10:90	5.5^{b}	5.7^{b}
HS 50:50	4.8^{a}	4.7^{a}
HS 75:25	4.6^{a}	4.5^{a}
F.prob	<0.001	<0.001
LSD (5%)	0.5	0.2

*means followed by different letters are significantly different (*p*=0.05)

Plant physiological responses to high E.C. and ammonium:nitrate ratio

The effects of high pore E.C. on physiological plant responses to the E.C. treatments for "Sonata" and Vibrant are shown in Figure 4 and Figure 5 respectively.

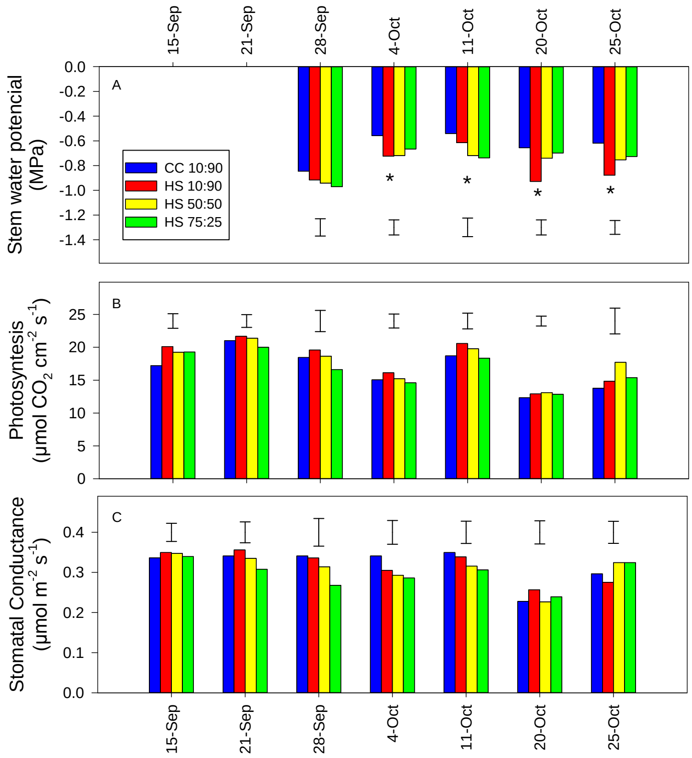

Figure 4. Effect of the four fertigation treatments on A) midday stem water potential, B) photosynthesis and C) stomatal conductance of "Sonata". Asterisks represent statistically significant differences between the treatments. Error bars represent LSD at 5%.

In both cvs., statistically significant reductions in midday stem water potential were detected between the treatments shortly after the coir pore E.C. reached the 3.5 mS cm^{-1} (target in the high E.C. treatments). In both cvs., plants in the CC treatment, where coir pore E.C. was kept below 2.5 mS cm^{-1}, had significantly lower midday stem water potential than those plants in the high E.C. treatment. This finding indicates that the latter were experiencing a water stress. Repeated measures analysis of variance for the dates where significant differences occurred, showed that for both cvs, whilst there was a significant difference between each high E.C. treatments and the low E.C. treatment (the CC) there were no significant differences between the high E.C. treatments receiving the different ammonium:nitrate ratios.

In “Sonata”, rates of photosynthesis and stomatal conductance were unaffected by the E.C. treatments, even when coir pore E.C. reached 3.5 mS cm^{-1} (Figure 4). In contrast, in “Vibrant” rates of photosynthesis and stomatal conductance were reduced in one of the high E.C. treatments (HS 10:90) on a couple of occasions it was measured, but not in HS treatments with higher levels of ammonium. In the second year experiment, photosynthesis and stomatal conductance in “Vibrant” was similarly affected when plants were exposed to high E.C., whilst “Sonata” as in this trial was unaffected by high coir E.C. Fruit extension rates were not affected by the E.C. treatments in “Vibrant”, whilst in “Sonata” it was reduced in the HS 10:90 treatment compared to the CC 10:90 on one occasion it was measured, there was no differences between the two treatments with higher ammonium inputs and the CC 10:90.

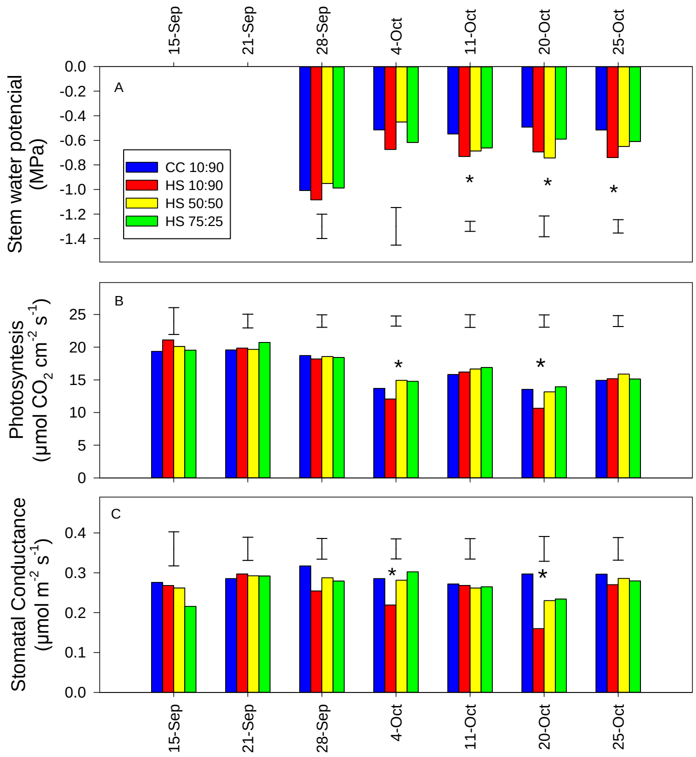

Figure 5. Effect of the four fertigation treatments on A) midday stem water potential, B) photosynthesis and C) stomatal conductance of "Vibrant". Asterisks represent statistically significant differences between the treatments. Error bars represent LSD at 5%.

Effect of high E.C. and ammonium:nitrate ratio on plant growth

Total above ground fresh biomass for plants of "Sonata" is significantly reduced in those in the high E.C. regimes, HS 10:90 and HS 50:50, when compared to the low E.C. regime (Table 2), CC 10:90, indicating that the plants in the former are under stress when the E.C. is kept consistently high, resulting in lower plant growth. However, plants in the high E.C. regime, HS 75:25, that had the highest amount of N supplied as ammonium did not suffer a reduction in plant biomass when compared to the CC 10:90 regime. Plants where pore coir E.C. builds up to high levels are better able to cope if they receive higher ammonium, performing as well as those experiencing low coir pore E.C. A similar result is seen with the total above-ground dry biomass (Table 2), which is significantly reduced in the plants in the HS 10:90 regime when compared to those from CC 10:90 regime, but for the regimes where there are higher amounts of ammonium applied, HS 50:50 and HS 75:25, dry weight was not significantly different to the low E.C. regime CC 10:90.

Table 2. The effects of the four fertigation regimes on individual plant fresh and dry weight– leaf, trusses and petiole; crown and total for "Sonata" at the end of the experiment.

	Fresh weight (g plant^{-1})				Dry weight (g plant^{-1})		
Treatment	Leaf, Trusses, Petiole	Crown	Total		Leaf, Trusses, Petiole	Crown	Total
CC 10:90	60.2^{b}	19.1	79.3^{b}		16.5^{b}	5.5	22.0^{b}
HS 10:90	42.1^{a}	18.0	60.1^{a}		12.3^{a}	5.7	17.9^{a}
HS 50:50	47.1^{a}	17.1	64.2^{a}		14.1^{ab}	5.1	19.2^{ab}
HS 75:25	56.1^{b}	18.6	74.7^{b}		15.6^{b}	5.5	21.1^{b}
F.prob	<.001	0.29	0.01		0.01	0.28	0.03
LSD (5%)	8.2	2.2	9.8		2.5	0.6	2.9

*means followed by different letters are significantly different (p=0.05)

In "Vibrant" the situation is less clear, there being no significant differences, in above ground fresh weight or dry weight, of plants in each of the high E.C. regimes when compared to the low E.C. regime (Table 3), CC 10:90. However, there is a significant increase in biomass between the plants in the HS 50:50 when compared to the other two high E.C. regimes. The "Vibrant" plants, in this trial, were not as vigorous and did not grow as well as those of "Sonata", largely due to the smaller size crowns that were used in "Vibrant".

Table 3. The effects of the four fertigation regimes on individual plant fresh and dry weight – leaf, trusses and petiole; crown and total for "Vibrant" at the end of the experiment.

	Fresh weight (g plant^{-1})				Dry weight (g plant^{-1})		
Treatment	Leaf, Trusses,	Crown	Total		Leaf, Trusses,	Crown	Total
CC 10:90	26.4^{a}	11.3	37.8^{a}		7.5^{a}	3.3	10.8
HS 10:90	23.8^{a}	10.7	34.4^{a}		7.1^{a}	3.5	10.7
HS 50:50	31.5^{b}	11.3	42.8^{b}		8.9^{b}	3.3	12.2
HS 75:25	23.4^{a}	10.5	33.9^{a}		7.0^{a}	3.1	10.1
F.prob	0.01	0.63	0.01		0.02	0.50	0.06
LSD (5%)	4.7	1.6	5.5		1.3	0.6	1.6

*means followed by different letters are significantly different (p=0.05)

Effect of high E.C. and ammonium:nitrate ratio on leaf nutrient concentration

In "Sonata" high E.C. (HS 10:90) caused a significant increase in Ca (7%) and Mg (13%) concentrations on leaves compared to the CC 10:90 treatment, while there was no effect on other macro- and micro-nutrients (Table 4). Higher ammonium rates at high E.C. (HS 50:50 and HS 75:25), increased N, Ca, Mg, S, Mn, Cu, Fe, Zn, and B leaf concentrations. The HS

50:50 treatments significantly decreased leaf K concentration and increased Ca compared to the rest of the treatments. Leaf S and Zn concentrations were higher on plants grown under the highest ammonium rate (HS 75:25).

In ”Vibrant” only Mg was affected by the high E.C. treatment (Table 5). Similar effects of the ammonium rate on leaf nutrient concentration were found in “Vibrant”. Both high ammonium rates increased N, P Mn, Cu, Fe, Zn and B concentrations compared to the low rates (CC 10:90, HS 10:90), there were not significant differences between them. In contrast, both of them decreased leaf K concentration. Calcium concentration was higher at HS 50:50 treatment, while Mg and S were higher at HS 75:25.

Table 4 The effects of the four fertigation regimes on leaf nutrient concentration for "Sonata".

Treatment	N	P	K	Ca	Mg	S		Mn	Cu	Fe	Zn	B
	$g\ kg^{-1}$							$mg\ kg^{1}$				
CC 10:90	19.4[a]	4.2	28.2[bc]	13.8[a]	3.0[a]	1.8[a]		118.7[a]	3.2[a]	50.4[a]	30.52[a]	40.0[a]
HS 10:90	19.6[a]	4.3	29.6[c]	14.8[b]	3.4[b]	1.9[a]		142.2[a]	3.4[a]	52.5[ab]	31.84[a]	39.1[a]
HS 50:50	20.9[b]	4.1	24.3[a]	15.8[c]	3.9[c]	3.8[b]		368.9[b]	4.1[b]	70.7[bc]	39.71[b]	57.1[b]
HS 75:25	21.8[b]	4.2	26.8[b]	13.6[a]	4.0[c]	4.62[c]		348.5[b]	4.2[b]	80.1[c]	43.54[c]	58.6[b]
F.prob	<0.001	0.66	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	0.01	<0.001	<0.001
LSD (5%)	1.1	3.3	2.1	7.9	233	501		38.9	0.5	19.6	2.9	3.6

*means followed by different letters are significantly different (*p*=0.05)

Table 5 The effects of the four fertigation regimes on leaf nutrient concentration for "Vibrant".

Treatment	N	P	K	Ca	Mg	S		Mn	Cu	Fe	Zn	B
	$g\ kg^{-1}$								$mg\ kg^{-1}$			
CC 10:90	20.7[a]	4.7[a]	29.3[b]	15.4[a]	2.9[a]	2.0[a]		161[a]	3.1[a]	70.0[a]	34.4[a]	39.2[a]
HS 10:90	20.1[a]	4.4[a]	30.0[b]	16.5[a]	3.3[b]	2.0[a]		209[a]	3.0[a]	67.9[a]	34.2[a]	37.0[a]
HS 50:50	23.3[b]	5.1[b]	26.2[a]	18.2[b]	3.7[c]	3.6[b]		477[b]	3.9[b]	142.6[b]	47.5[b]	56.0[b]
HS 75:25	24.2[b]	5.3[b]	27.6[a]	16.0[a]	4.3[d]	5.5[c]		476[b]	4.0[b]	131.5[b]	46.9[b]	58.1[b]
F.prob	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001
LSD (5%)	1.1	3.9	14.6	1242	200	299		49.7	0.2	18.7	2.6	3.4

*means followed by different letters are significantly different (*p*=0.05)

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

In “Sonata” plants grown in the low E.C. regime, CC 10:90, the total yield of Class I and 2, small and waste were 206, 10 and 35 g per plant, respectively (Figure 6). Those plants grown in the high E.C. regime with the same ammonium:nitrate ratio (HS 10:90) as the CC had a significantly reduced Class I yield, only cropping 167 g per plant, approximately 20 % less. This was due to reduced number of Class I berries, 17 per plant in the HS 10:90 compared to 20 in the CC 10:90, the total number of berries per plant was similar between the two treatments, 29 (CC 10:90) and 28 (HS 10:90) but there were more berries in the smaller Class II and waste category. The reduction in yield was due to the high E.C. reducing berry size, this was confirmed with the FER which were also reduced in the HS 10:90 treatment. However, whilst there was a reduction in Class I fruit number (approx. 5%) and weight (approx. 10%) in the other high E.C. regimes (HS 50:50 and HS 75:25) compared to the CC 10:90, this was not statistically significant, but both these regimes yielded significantly better than the plants in the high E.C. treatment that did not receive the additional ammonium-N.

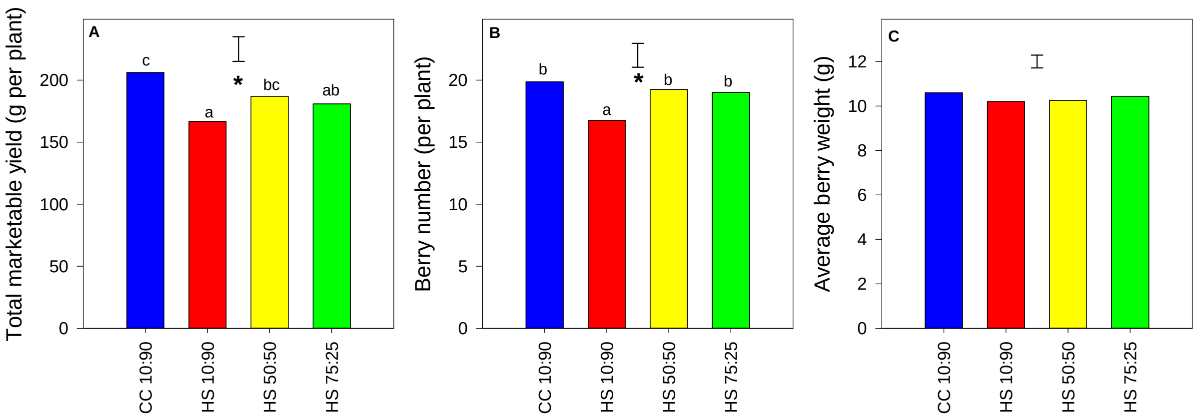

Figure 6. Effect of the four fertigation treatments on A) total marketable yield B) total berry number and C) average berry weight, of “Sonata”. Asterisks represent statistically significant differences between the treatments, where significant bars with different letters are significantly different from one another. Error bars represent LSD at 5%.

The “Vibrant” plants cropped about half as much as the “Sonata” plants, again due to the smaller sized crowns of the propagation material that was planted. Those grown in the low E.C. regime, CC 10:90, yielded fruit in Class I, small and waste of 102, 9 and 17 g per plant, respectively (Figure 7). As in “Sonata” those plants grown in the high E.C. regime with the same ammonium:nitrate ratio (HS 10:90) as the CC 10:90 had a significantly reduced Class I yield, only cropping 83 g per plant, approximately 18 % less than the CC, this was due to a combination of reduced number of Class I berries and also smaller Class I berries. Those plants in the high E.C. regimes receiving the additional ammonium-N, HS 50:50 and HS 75:25, had the same Class I yields as the CC 10:90, despite being grown with high coir E.C. these performed as well as those in the low coir E.C.

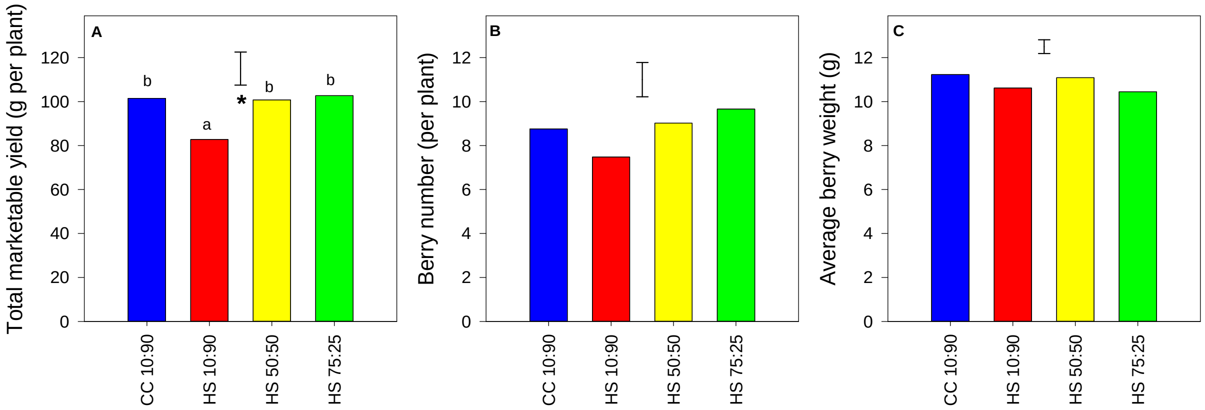

Figure 7. Effect of the four fertigation treatments on A) total marketable yield B) total berry number and C) average berry weight, of "Vibrant". Asterisks represent statistically significant differences between the treatments, where significant bars with different letters are significantly different from one another. Error bars represent LSD at 5%.

There were no significant treatment effects on fruit firmness in "Sonata", with an average firmness over the last 4 measurement dates (i.e. when high pore coir E.C. had become established in the high E.C. treatments) ranging from 3.25 N for the HS 75:25 and 3.40 N for the HS 10:90. Repeated measures ANOVA, showed that there was no significant difference in berry firmness between the treatments (Table 7). The higher ammonium-N did not result in softer fruit. Soluble solids content (%BRIX) in "Sonata" was significantly increased in the HS 10:90 regimes when averaged over the last 4 dates measurements, by 0.8-1.2%, when compared to the other regimes, there being no difference between the CC 10:90 and the other two high E.C. regimes (HS 50:50 and HS 75:25). There were also significant differences between treatments in the concentration of Malic Acid (Table 6), with a significant reduction in all the high E.C. treatments compared to the CC, and also total acid concentrations were significantly reduced for the HS 50:50 and HS 75:25. Whilst TEAC and sucrose were not significantly different between the treatments they were approaching significance; TEAC levels were higher in the HS 10:90 and HS 75:25 than the CC whilst sucrose was highest in the HS 10:90 compared to the CC. There were no significant differences between the treatments for the other sugars and acids did not differ between the treatments.

Table 6. The effects of the four fertigation regimes on organic acid and sugar concentrations, Trolox equivalent antioxidant capacity (TEAC), % berry dry matter (DM) and sugar to acid ratio for "Sonata". Data is the average of fruit sampled on 3 occasions and statistically analysed with repeated measures.

Treatment	DM	Ascorbic acid	Citric Acid	Malic Acid	Total Acid	TEAC
	%	mg g^{-1} DM				μmol Trox g^{-1} DM
CC 10:90	13.3	4.5	80.4	29.2[c]	114[b]	84.4
HS 10:90	13.7	4.5	76.9	24.9[b]	106[ab]	89.4
HS 50:50	12.5	4.4	74.4	21.6[a]	100[a]	84.3
HS 75:25	12.2	4.4	74.7	20.8[a]	100[a]	90.2
F.prob	0.02	0.86	0.39	<0.001	0.01	0.06
LSD (5%)	1.0	0.2	7.9	2.5	8.9	5.5

Treatment	Fructose	Sucrose	Glucose	Total Sugar	Sugar:Acid ratio
	mg g^{-1} DM				
CC 10:90	248	258	244	750	6.9
HS 10:90	242	288	241	772	7.6
HS 50:50	238	260	235	733	7.7
HS 75:25	241	246	236	723	7.7
F.prob	0.46	0.06	0.51	0.18	0.20
LSD (5%)	12.4	30.7	13.8	46.7	0.9

*means followed by different letters are significantly different (p=0.05)

There were no significant treatment effects on fruit firmness in "Vibrant" (Table 7), with an average firmness over the last 4 measurement dates (i.e. when high pore coir E.C. had become established in the high E.C. treatments) of 2.6 N, with no significant differences between the 4 treatments. The higher ammonium-N did not result in softer fruit. Soluble solids content (%BRIX) in "Vibrant" was significantly increased in the HS 10:90 regimes when averaged over the last 4 dates measurements, by up to 0.9%, when compared to the other regimes, there being no difference between the CC 10:90 and the other two high E.C. regimes (HS 50:50 and HS 75:25).

Table 7. The effects of the four irrigation fertigation on Firmness (at 8 mm) and soluble sugar content (Brix (%)) for "Sonata" and "Vibrant". Data is the average of fruit sampled on 4 occasions and statistically analysed with repeated measures.

	"Sonata"		"Vibrant"	
	Firmness (N)	Brix (%)	Firmness (N)	Brix (%)
CC 10:90	3.36	11.2[a]	2.56	9.2[a]
HS 10:90	3.40	12.0[b]	2.59	9.9[b]
HS 50:50	3.27	10.9[a]	2.41	9.5[ab]
HS 75:25	3.25	10.8[a]	2.41	9.2[a]
F.prob	0.65	0.02	0.07	0.03
LSD (5%)	0.3	0.8	0.2	0.5

*means followed by different letters are significantly different (p=0.05)

Discussion

Salt stress effects on strawberries

Strawberry cvs. differ in their response to high E.C. and the complexity in the salt-stress adaptation of the plants is determined by many interacting environmental variables. In our experiments high E.C. depressed plant growth on "Sonata". In contrast to the 2015/16 trials, high E.C. did not affect Vibrant's biomass production. Similar, results were found for "Elsanta", "Korona" and "Camarosa" (Rahimi and Biglarifard, 2011; Saied et al., 2005) and the effect of E.C. may differ between growing seasons (Saied et al., 2005). At the growing season 2016/17, no visual symptoms of E.C. stress were observed.

Salinity stress can affect several physiological and metabolic processes such as photosynthesis, N assimilation, phytohormone turnover, respiration, and protein synthesis (Munns, 2002). Our results agree with Turhan et al. (2008) who that found genotypic difference on strawberries' physiological responses to E.C.. High E.C. reduced stomatal conductance and photosynthesis rate only in "Vibrant". A fall in midday stem water potential is one of the most sensitive physiological responses to stresses; in our experiment stem water potential was reduced in both cvs. indicating that they are experiencing a degree of stress by high E.C.

Under salt stress, nitrate uptake is slowed down by Cl accumulation and its competition and reduces nitrate assimilation with the possible consequences of N deficiency in the plant (Manzoor Alam, 1999), however, this was not observed in our experiments. Frequently, plants exposed to NaCl inevitably absorb a large amount of Na which subsequently causes a decrease in the contents of K, Mg and Ca (Manzoor Alam, 1999). No effect of the high E.C. on leaf K concentration was observed in any of the cvs. A similar response was found when “Korona” and “Elsanta” were exposed to NaCl stress (Keutgen and Pawelzik, 2009; Rahimi and Biglarifard, 2011; Saied et al., 2005). The same authors found that Ca and Mg were decreased in leaves as the E.C. increased but the opposite observed for “Sonata” and “Vibrant”.

The reduction of fruit yield was due to a reduction of fruit numbers, whereas averaged berry size remained the fairly constant. Saied et al. (2005) found similar results for “Korona” and “Elsanta”. Strawberry fruit is highly susceptible to bruising and post-harvest decay and low levels of Ca exacerbate the problem, reducing shelf life. Standard commercial quality characteristics (firmness and Brix) were not affected by the treatments although there are reports that salinity can influence texture and taste (Saied et al., 2005). The increase of plant Ca may have ameliorated the negative effects of high E.C. on berry firmness. Strawberry cvs. differ in their contents of soluble carbohydrates (fructose, sucrose, glucose, etc.) and organic acids (citric acid, ascorbic acid, malic acid, etc.) (Kafkas et al., 2007; Keutgen and Pawelzik, 2008). The effect of salinity level on organic acids and sugar concentration is genotype dependent (Keutgen and Pawelzik, 2008). Further fruit quality characteristics were analysed for “Sonata” on 3 occasions and revealed that high E.C. did not affect sugar and organic acid concentrations in our experiments.

Effects of ammonium:nitrate rate on ameliorate high E.C. stress

Previous studies have shown that when strawberries are grown under optimal E.C. level with a high ammonium rate (75%), strawberry leaf fresh and dry weight is reduced (Tabatabaei et al., 2006). However, when we grew “Sonata” under high E.C. conditions and increased the ammonium:nitrate ratio from 10:90 to 75:25 this resulted in an increased fresh vegetative biomass production of 24%. Stimulatory effects on plant growth with a low concentration of ammonium have been associated with plant energy savings. Nitrate needs to be reduced to ammonium before incorporation into amino acids. This is an energy-dependent process requiring 20 molecules of ATP, in contrast, ammonium assimilation requires only 5 molecules of ATP (Barker and Bryson, 2006). Energy savings during N assimilation when the 75:25 ammonium:nitrate ratio was used at high E.C. might allow more resources to be allocated to energy-requiring salt tolerance mechanisms.

Increasing the ammonium:nitrate ratio from 10:90 to 50:50 increased its fresh vegetative biomass production by 24%. However, further increases to the ammonium:nitrate ratio decreased the positive effects on the biomass production, similar results were found for strawberries grown under optimal E.C. conditions (Tabatabaei et al., 2006). This may be attributed to the fact that when ammonium is provided at relatively high concentrations, its uptake may exceed the assimilatory capacity or change the ionic equilibria leading to toxicity (Barker and Bryson, 2006). Such effect although was not evident in “Sonata”, it is possible to have been caused in “Vibrant” due to the restricted plant growth.

Competition between ammonium and Na for root uptake sites have been suggested as the cause of the decrease in Na uptake and transport from roots to shoots at different plant species (Ghanem et al., 2011; Kant et al., 2007). Moreover, growth stimulation by the higher ammonium rate may have diluted deleterious effects of toxic anion accumulation. High ammonium rate increased most macro- and micro-nutrient concentration on both cvs. and better nutritional status can help ameliorate salinity stress. Ghanem et al. (2011) found that higher ammonium rate improved tomato’s K status and it could explain partly the higher N concentrations at salt-treated plants. However, in strawberries high ammonium rate decreased leaf K concentration, this can be due to a negative interaction between ammonium and K, similar results were found in canola (Bybordi, 2012).

From the results of this experiment, it can be concluded that improved plant nutrient status by the higher ammonium rate counteracted the deleterious effects of salinity stress on the plant growth, physiological responses and yield, helped the strawberry plants to avoid ion toxicity and improved cell membrane stability and nutrient uptake under salinity stress. 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. The project results suggest that optimum fertigation management and nutrient balance can ameliorate the negative effects of salinity and ensure constant yield and quality.

Overall project conclusions

- In “Sonata” and “Vibrant”, water savings of 36% and 5% were achieved, respectively, without reducing yields of Class I fruit
- In “Sonata” and “Vibrant”, fertiliser savings of 36% and 5% were achieved, respectively, without reducing yields of Class I fruit. Foliar macro and micro nutrient concentrations were within satisfactory ranges
- A new irrigation scheduling tool has been developed using irrigation set point based on coir volumetric moisture contents. This approach has the potential to deliver significant water and fertiliser savings in commercial “Sonata” and “Vibrant” production without reducing marketable yields and quality.

- Substrate E.C. was increased by 34% under the DD regime by the end of the experiments
- Yields of both “Vibrant” and “Sonata” was significantly reduced when coir E.C. was maintained above 3.5 mS cm^{-1} during cropping.
- However, in both “Vibrant” and “Sonata”, when coir E.C. was maintained above 3.5 mS cm^{-1} yields were significantly increased when the amount of ammonium applied was increased to 50 or 75% of the N applied.
- In “Sonata” high E.C. without a change in the ammonium:nitrate (10:90) reduced plant biomass, whereas increasing ammonium:nitrate ratio to 75:25 improved plant biomass so that it was no different to that of the plants grown in low coir E.C.
- High ammonium application did not affect fruit firmness
- Higher ammonium application decreased coir pH
- Nutrient formulations need to be refined for each cv to avoid toxicity, foliar desiccation and yield reduction at higher coir pore E.C. levels

Knowledge and Technology Transfer

- Project aims, objectives and results were presented at the AHDB Soft Fruit Day, 22 November 2016, NIAB EMR.
- Project aims, objectives and results were presented in an article presented in the HDC Soft Fruit agronomist day, January 2017
- Project aims, objectives and results were presented in an article published in the Soft Fruit HDC review magazine, February 2017

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