Project title:	Deriving irrigation set points to improve water use efficiency, fruit quality and sustainability of irrigated high intensity apple and sweet cherry orchards
Project number:	TF 210
Project leader:	Dr Mark A. Else, East Malling Research
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Location of project:	East Malling Research
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Date project commenced:	1 April 2013
Date project completed:	31 March 2016

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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Grower Summary

Headlines

- It is not necessary to apply frequent irrigation events to maintain the soil near to field capacity to deliver good commercial yields in 'Gala/M.9' and 'Braeburn/M9'.
- Adopting the Alternate Wetting and Drying (AWD) irrigation regime with a lower set point of -200 kPa (matric potential averaged throughout the rooting zone) from 6 weeks after full bloom until harvest will optimise both on-farm water use efficiency and crop productivity in 'Gala/M.9' and 'Braeburn/M9'.
- In 'Merchant/Gisela5', mild soil drying during fruit growth Stage 1 will significantly reduce both yield and number of Class 1 fruit per tree
- Significant saving of water (and fertilisers) can be achieved without reducing Class 1 yields of 'Kordia/Gisela5' and 'Merchant/Gisela5' if AWD is used with lower irrigation set points of -60 and -200 kPa during Stages I-II, and III respectively.

Background and expected deliverables

The tree fruit sector is increasingly reliant on irrigation to deliver the fruit size and quality demanded by retailers and consumers. However, the move to more intensive growing systems and the impacts of climate change on evaporative demand and summer water availability mean that irrigation water needs to be used more efficiently. Under the Government's Abstraction Licence Reform programme, drip irrigators will no longer be exempt from abstraction licencing and when implementation of the new system begins in November 2016, drip irrigators will have to demonstrate an efficient use of irrigation water.

The challenge is to put in place measures that improve irrigation water productivity, especially in areas of water vulnerability, but also maintain or improve marketable yields and consistency of fruit quality at harvest and after removal from store. In Project TF 198, scientists at East Malling Research developed an alternate wetting and drying (AWD) irrigation regime for high-intensity pear production. Irrigation was applied at a pre-determined irrigation set point; this was informed by measuring the trees' responses to declining water availability throughout the cropping season. The duration of each irrigation event was adjusted to ensure that the soil throughout the rooting zone was returned to field capacity. The AWD approach delivered water savings of over 50%, compared to current commercial practice, and yields and quality of marketable fruit were maintained. AWD is now being tested on a commercial farm in a project funded by a major retailer and a leading tree fruit Producer Organisation. In this Project, a similar approach has been used to identify, develop and test water-saving irrigation set points for apples (Gala/M.9, ‘Braeburn/M9’) and cherries (‘Kordia/Gisela5’ and ‘Merchant/Gisela5’).

Summary of the project and main conclusions

Years 1 and 2

- It is not necessary to apply frequent irrigation events to maintain the soil near to field capacity throughout the season to deliver good commercial yields in ‘Gala/M9’ and ‘Braeburn/M9’. This approach will increase leaching of N and other nutrients past the rooting zone.
- Adopting AWD and using an irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) from six weeks after full bloom until harvest, will optimise both on-farm water use efficiency and crop productivity in ‘Gala/M.9’ and ‘Braeburn/M9’. It is important that soil is returned to field capacity following each irrigation event.
- Soil should be maintained at or near to field capacity from anthesis until six weeks after full bloom to prevent potential detrimental effects of soil water deficits on marketable yields.
- In ‘Kordia/Gisela5’, average soil matric potentials fell to -65, -218, -581 and -900 kPa in the Deficit Irrigation (DI) treatments imposed at stages I, II, III and post-harvest, respectively. Rates of photosynthesis were similar irrespective of treatment and there were no significant treatment effects on’ Kordia’ Class 1 yields, which ranged from 1.6 to 3.2 Kg per tree.
- In ‘Merchant/Gisela5’, average soil matric potentials fell to -115, -22, -332 and -925 kPa during the four DI treatments. The mild soil drying imposed during Stage 1 significantly reduced both yield (2 Kg vs 3 Kg) and number (172 vs 285) of Class 1 fruit per tree, compared to the CC treatment where soil was maintained around field capacity.

Year 3

To optimise irrigation water productivity when using AWD, the frequency and duration of irrigation events must be managed carefully to avoid run-through of water and nutrients past the rooting zone. To achieve this, information on changes in soil water availability and soil moisture content at different depths within the rooting zone throughout the season is needed. In this project, Decagon MPS2 sensors, which measure soil matric potential, and Decagon 10HS sensors, which measure soil volumetric moisture content, were used to provide this information.

Two experiments were conducted on the sweet cherry varieties 'Kordia/Gisela5' and 'Merchant/Gisela5':

1) The effects of soil moisture deficits during the flower initiation phase (the post-harvest treatment) in 2014 on yields and quality of 'Kordia' and 'Merchant' Class 1 fruit in the subsequent cropping year (2015).
2) In 2015, soil matric potential was maintained above -60 kPa during Stages I and II, then different irrigation set points were tested during Stage III in each cultivar, and treatment effects on Class 1 yields were compared to those under the Commercial Control (CC) regime.

Experiment 1

In 2014, five treatments were applied; a CC treatment to maintain the average soil matric potential above -20 kPa throughout the season (well-watered, field capacity), and four DI treatments of different duration and intensity that were imposed during fruit growth stages I (cell division), II (pit hardening) and III (cell expansion), and postharvest during the flower initiation stage; at all other stages, soil was maintained near to field capacity (see TF 210 Annual Report 2015). The effects of these treatments on return bloom, marketable yield and quality in the subsequent cropping year (2015) was determined.

Results

The DI treatments applied during the different growth stages in 2014 had no statistically significant effects on return bloom, fruit bud number, Class 1 yield or fruit quality in either variety in 2015. The most significant soil drying was imposed post-harvest in 2014 (ITR3) and published work reported that fruit yields and quality of 'New Star' could be reduced in the subsequent cropping year following post-harvest water stress applied to control vegetative vigour. However, Class 1 yields and individual fruit fresh weights of both 'Kordia/Gisela5' and 'Merchant/Gisela5' were unaffected by the ITR3 treatments applied in the previous season.

Experiment 2

The aim was to test whether the irrigation set points derived in 2014 maintained fruit yields and quality whilst significantly reducing water inputs. In 2015, three irrigation treatments were imposed (Figure 1);

1) A well-watered commercial control (CC) where irrigation decisions were taken by EML's Farm Manager Mr Graham Caspell;
2) An Irrigation Test Regime 1 (ITR1) where soil matric potential was maintained above -60 kPa during Stages I and II, and above -200 kPa during Stage III and post-harvest;

3) An Irrigation Test Regime 2 (ITR2) where soil matric potential was maintained above -60 kPa during Stages I and II, and during Stage III and post-harvest, irrigation was withheld until leaf physiological responses were detected. Irrigation was then applied to return soil to field capacity and thereafter, irrigation was applied once the soil matric potential reached -200 kPa.

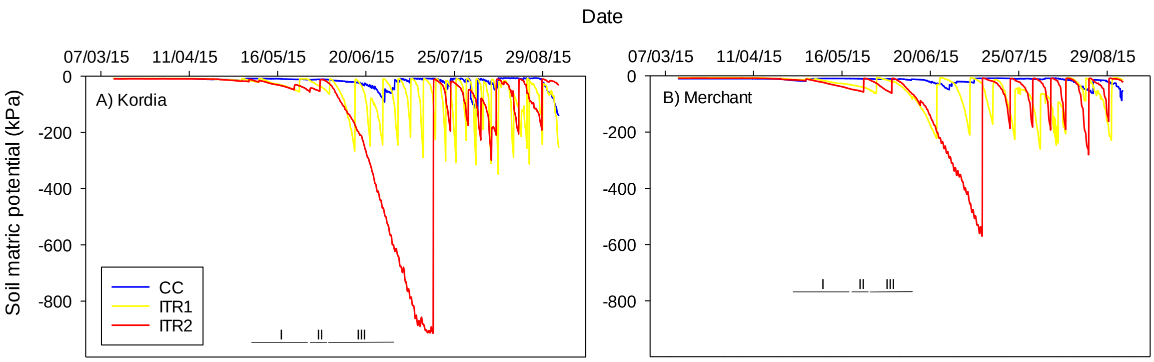

Figure 1. Changes in soil matric potential averaged over the top 60 cm of soil in each of the three irrigation treatments applied to A) ‘Kordia/Gisela 5’ and B) ‘Merchant/Gisela 5’ trees in 2015.

Results

Leaf physiological responses were measured to assess whether trees were experiencing soil water deficit stress under the ITR1 and ITR2 treatments. On 17 July 2015 during the post-harvest period, midday stem water potentials of ‘Kordia/Gisela5’ trees under the ITR1 treatment measured at the irrigation set point of -200 kPa, were significantly reduced compared to CC values; however, *Pn* and g_s were unaffected by the ITR1 treatment on that date, indicating that trees were experiencing a mild but transient soil water deficit stress. In the ITR2 treatment, midday stem water potential was reduced significantly, compared to the CC treatment when measured on 29 June 2015, one day prior to harvest, but was not affected 4 days earlier. Photosynthesis was also reduced significantly in the ITR2 treatment during this time, when average soil ψ_m ranged from -430 to -599 kPa in the ITR2 treatment. Stomatal conductance was reduced significantly at an average soil ψ_m of -900 kPa which occurred during the post-harvest stage.

However, although trees in the ITR1 and ITR2 treatments showed signs of mild water deficit stress, Class 1 yields did not differ significantly between treatments, with yields of 6.7, 7.0 and 8.6 kg per tree from the CC, ITR1 and ITR2 treatments, respectively. Individual fruit weight was reduced significantly in the ITR1 (11.9 g) and ITR2 (11.8 g) treatments, when compared to the CC (12.6 g); there was no evidence that limited soil water availability in the ITR treatments limited fruit expansion and this effect was likely due to differences in crop load. There were no differences in fruit firmness or %BRIX between the treatments. Total water application to each tree was 1,622, 450 and 244 L for the CC, ITR1 and ITR2 trees respectively.

'Merchant/Gisela5' under the ITR1 treatment showed reduced midday stem water potentials on 14 July 2015, indicating that they were experiencing a mild water deficit stress at an average soil ψ_m of -200 kPa. In the ITR2 treatment, physiological responses were triggered at an average soil ψ_m between -475 and -550 kPa, but again, these responses occurred post-harvest. There were no significant treatment differences in Class 1 yields, which averaged 6.9, 5.9 and 5.7 kg per tree under the CC, ITR1 and ITR2 regimes respectively. Individual fruit weight was not significantly different between treatments with values of 11.0, 11.1 and 10.8 g for the CC, ITR1 and ITR2 treatments respectively. There were no differences in fruit firmness or % BRIX between the treatments. Total water application to each tree was 1,754, 209 and 188 L for the CC, ITR1 and ITR2 trees, respectively.

Main conclusions

Many tree fruit growers use irrigation to maintain soil moisture around field capacity throughout much of the cropping season, since mild or severe soil moisture deficits can limit rates of fruit expansion. However, this approach can lead to significant leaching of water and fertilisers and any rain that falls within the cropping season is not utilised effectively. This research has shown that irrigation may not be necessary in years when sufficient rainfall occurs at regular intervals throughout the cropping season. Nevertheless, to ensure consistency of yields of Grade I fruit in successive cropping seasons, drip irrigation is essential to avoid soil moisture deficits that limit fruit expansion.

Stone fruit growers growing under covers rely on irrigation to optimise yields and fruit quality but excessive irrigation prior to harvest can result in the skin of fruit rupturing on the way to the pack house. The alternate wetting and drying approach developed in this project will optimise both resource use efficiency and Class 1 yields and quality, without adverse effects on return bloom, yields or quality of 'Kordia/Gisela5' and 'Merchant/Gisela5', provided that the irrigation set points of -60 and -200 kPa are used in growth stages I-II and III, respectively. The outputs of this research will also enable those stone fruit growers who do not use covers to schedule their irrigation more effectively around seasonal rainfall events.

A key output of this research project has been the identification of the range of soil water availabilities over which Grade 1 yields, fruit quality and storage potential are optimised in apple and sweet cherry varieties. Sensors that measure changes in soil moisture availability at different rooting depths have been used in experiments to trigger irrigation automatically, so that soil water availability is optimised, whilst leaching of water and nutrients is minimised. Access to this information can now be gained remotely using an 'App' developed for smartphones which provides alerts to tree fruit growers of the need to irrigate. The automated precision irrigation system can also be used to apply DI during specific crop development stages, in an attempt to improve aspects of fruit quality, without reducing fruit size. The challenge now is to incorporate environmental metrics and weather probability forecasting into a grower-facing irrigation decision support system. This will enable soil water availability to be optimised during specific cropping stages in changeable weather by making the most effective use of rainfall in tree fruit production, and by scheduling irrigation effectively to protected stone fruit crops.

Financial benefits

The true economic value of water used for the irrigation of high-intensity tree fruit orchards is difficult to quantify, as are the financial benefits associated with water savings (unless mains water is used as a source of irrigation water). In EMR's ERDF-funded WATERR project, data gathered from tree fruit growers suggested that optimising irrigation timing and duration is more important than improving water use efficiency per se, in maximising returns. The top 50% of apple growers (in terms of financial returns) used twice as much water per tonne than other growers, and also applied three times more irrigation water per hectare, but their achieved average yields of 31 tonnes per hectare were 55% higher than other growers. The growers estimated the financial benefit of irrigation to be ~15% of their gross proceeds. The importance of irrigation in helping growers to optimise fruit size and quality was also reflected in the fact that, on average, the top 50% of apple growers achieved crop selling prices that were 34% higher than other producers. These top 50% achieved average net proceeds after irrigation costs of £20,000 per hectare compared with £10,000 per hectare for other growers.

The top 50% of pear producers in terms of financial returns achieved net proceeds after irrigation costs of £17,000 per hectare on average, compared with £12,000 per hectare for other growers. On average, there was little difference in yields between the top and bottom 50% of growers, with overall average yields of 23 and 22 tonnes, respectively. Likewise, both groups used similar volumes of water per tonne and per hectare. However, the importance of irrigation scheduling and timing in helping growers to optimise fruit size and quality is reflected in the fact that on average the top 50% of growers achieved crop selling prices that were 34% higher than other producers.

Action points for growers

- Consider installing sensors to measure soil water availability or soil moisture content within the rooting zone to help develop effective irrigation scheduling strategies.
- Consider installing water meters to record accurately the volumes of water used to produce 1 tonne of Class 1 fruit.
- Monitoring water inputs and changes in soil water availability/content in just one block will help to improve awareness of the effectiveness of current irrigation strategies and will highlight opportunities for improvement.
- For ‘Gala/M.9’ and ‘Braeburn/M.9’, maintain soil around field capacity during flowering and for six weeks after full bloom. Using the AWD approach with a lower irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) from six weeks after full bloom will optimise both on-farm water (and fertiliser) use efficiency and crop productivity.
- Significant saving of irrigation water can be achieved without reducing Class 1 yields of ‘Kordia/Gisela5’ and ‘Merchant/Gisela5’ if AWD is used with lower set points of -60 and -200 kPa during Stages I-2, and III respectively.

Science Section

Introduction

Irrigation is essential for the successful establishment and continued productivity of high-intensity tree fruit growing systems[1]. Modern and traditional orchards rely increasingly on irrigation to deliver the consistency of yields and quality needed for a profitable business[2]. In Kent, the volume of water used for trickle irrigation has more than doubled in the last 10 years to 2,000 Mega Litres (ML)[3]. Ninety per cent of tree fruit growers farm in areas where water resources have already been classified by the Environment Agency (EA) as under increasing stress and abstraction rates in these areas are currently unsustainable[4]. Recent droughts, particularly affecting the south-east and east regions, and predictions of the impacts of climate change on water availability, have highlighted the need for growers to use irrigation water more efficiently. During recent visits to farms conducted as part of a European Regional Development Fund (ERDF) project on improving water availability and increasing water use efficiency in the south-east (WATERR), many tree fruit growers were very concerned about future water availability and the likely impact of any restrictions on their businesses.

Trickle/drip irrigators have so far been exempt from legislation designed to safeguard resources and limit damage to the environment (*e.g.* Water Framework Directive 2000, Water Act 2003). However, this exemption will be removed as part of the overhaul of the abstraction licencing system, and the process will begin in November 2016. In future, all drip irrigators will require an abstraction licence and they must also be able to demonstrate a need for, and an efficient use of, irrigation water before time-limited abstraction licences are renewed. Achieving the 'good status' for water quality set out in the Water Framework Directive is proving challenging in the UK and elsewhere, and so there is also increasing pressure on the agriculture and horticulture industries to minimise the impacts of intensive production systems on surface water and ground water quality.

If UK tree fruit growers are to maintain or increase yields against a backdrop of increasing summer temperatures, dwindling water supplies, and governmental demands for greater environmental protection, new production methods that improve water and nutrient use efficiency and utilise 'best practice' are needed. Although irrigation 'best practice' guidelines are available, they were developed overseas and new improved guidelines are needed for use by UK tree fruit growers to ensure that high yields of quality fruit with good shelf-life potential can be produced in an environmentally sustainable way. Our research with soft fruit crops has shown that water savings of up to 80% can be achieved compared to current 'best practice' using the approaches to irrigation scheduling developed at EMR. In commercial trials, Class 1 yields and aspects of fruit quality were also improved and fertiliser savings of up to 36% were achieved[5].

In HDC-funded research in the Concept Pear Orchard at EMR (TF 198), we developed an AWD irrigation strategy based on soil matric potential (ψ_m) that delivered water (and fertiliser) savings of between 50 and 77% without reducing Class 1 yields or fruit quality[6]. The Tree Fruit Panel recognised the significant opportunity to use a similar approach to improve resource use efficiency in high-intensity apple and sweet cherry production. Because soil ψ_m is not influenced by changes in soil bulk density, the irrigation scheduling guidelines developed in this research will be relevant to the range of different soil types used for apple and cherry production in the UK. These guidelines will also provide the basis for future research work on developing Deficit Irrigation (DI) regimes to control vegetative growth, influence dry matter partitioning, improve fruit quality and storage potential and optimise the use of valuable resources.

In this project, irrigation test regimes (ITRs) were developed for two apple and two sweet cherry varieties to try to optimise water use efficiency (WUE) without reducing Class 1 yields or quality. Our approach was to impose temporary and gradual soil drying so that tree physiological responses to limiting soil water availability *e.g.* lowered stomatal conductance, photosynthesis, midday stem water potential and fruit expansion rate, were triggered. The range of soil ψ_m within the rooting zone at which these responses began to diverge significantly from well-watered values were then identified. This process was repeated at different stages of crop development, enabling irrigation set points for each of the fruit growth stages to be developed and tested under prevailing weather conditions (*e.g.* evaporative demand). In further work, the lower irrigation set point at each developmental stage was set at 100 kPa above the value that tree physiology becomes affected (ψ_m values are negative). Using the AWD approach, irrigation was only applied once the lower set-point has been reached and the duration of irrigation was adjusted to ensure that the soil is returned to field capacity (*ca*. -10 kPa) whilst minimising the loss of water past the rooting zone.

The timing and extent of soil water deficits must be controlled carefully to avoid crop losses, due either to reduced fruit size, fewer fruit or effects on return bloom. In sweet cherry, limited soil water availability during stage I of fruit growth can limit fruit size but trees are more tolerant to soil drying during stage II of fruit growth. Large variation in soil water availability during stage III can induce cracking in some varieties and so this should perhaps be avoided. Soil water deficits post-harvest applied to suppress vegetative growth can also reduce fruit firmness and SSC after cold storage in the following year[7], presumably through effects on assimilate partitioning during the time of flower bud initiation. Clearly, it is important to identify the irrigation set points that maintain fruit yields and quality. Plant midday stem water potential (ψ_{ms}) threshold values above which fruit size, number and quality are unaffected have been derived overseas for 'New Star'[7] and 'Brooks'[8], and this work helped to inform our strategies for developing efficient irrigation regimes for 'Merchant/Gisela5' and 'Kordia/Gisela5'. Similar threshold values of ψ_{ms} have been derived for several apple cvs and these were compared against those found to limit fruit size and number in 'Gala/M.9' and 'Braeburn/M.9. Knowledge of the soil matric and ψ_{ms} values that limit yield and productivity will inform the development of irrigation guidelines that optimise resource use efficiency whilst maintaining or improving marketable yields and fruit quality.

Materials and Methods

In 2015, two experiments were conducted on cherry varieties 'Kordia/Gisela5' and 'Merchant/Gisela5' in a mixed cultivar orchard at EMR. The aim of Experiment 1 was to determine the effects of the irrigation treatments applied in 2014 on return bloom, marketable yield and quality in the subsequent cropping year, 2015. The aim of Experiment 2 was to test whether the irrigation guidelines developed in 2014 maintained marketable yields and fruit quality whilst significantly reducing water and fertiliser inputs.

The orchard was planted on 22 April 2011 at an in-row spacing of 3 m between trees, with 3 m between each row in staggered double rows and 4 m between each double row. Each double row contained a single variety and each tree was supported by a Nº6 tree stake. Tree branches were tied down immediately after planting. All trees within the orchard received the same crop husbandry practices (*e.g.* pest and disease spray programmes, fertiliser application, weed control). Until the beginning of this project, the frequency and duration of irrigation applied to all trees was the same, irrespective of variety. Irrigation water was supplied by pipes running along each row on the ground, with 1.6 L h^{-1} emitters positioned 60 cm apart. All rows were covered by polytunnels on 20 April 2015 until the end of July 2015 when the covers were removed post-harvest. Fertigation was applied from 6 May until 3 August 2015, and irrigation continued until 4 September 2016.

Experiment 1

Experimental design

In 2014, five treatments were applied; a Commercial Control (CC) treatment in which the average soil matric potential over the top 60 cm of soil was maintained above -20 kPa throughout the season (well-watered, field capacity), and four DI treatments of different durations and intensities that were imposed during fruit growth stages I (cell division), II (pit hardening) and III (cell expansion), and post-harvest during the flower initiation stage. At all other stages, soil was maintained near to field capacity (see TF 210 Annual Report 2015). In 2015 when the effects of the previous year's treatments on return bloom, marketable yields and fruit quality were determined, all trees were irrigated under the CC regime.

Blossom count

The total numbers of flower buds on the experimental trees were counted on 13-14 May 2015.

Fruit yield and quality

Fruit was harvested from 'Kordia/Gisela5' trees on 1 July 2015 and from 'Merchant/Gisela5' trees on 26 June 2015. The total number and fresh weight of fruit from each tree was recorded. Fruit were separated into fruit without defects, those with rots, cracks or any other disorder and the total number and weight for each category was recorded. For fruit quality measurements, a fifty fruit sub-sample of marketable fruit was selected at random to record the size variation for each tree. Two other sub-samples of five fruit were also taken, one for measurement of fruit firmness using a FirmTech 2 and the other to measure Soluble Sugar Content (SSC) with a digital refractometer.

Experiment 2

Experimental design

In 2015, three irrigation treatments were imposed on each variety;

1) Well-watered, commercial control (CC) treatment where irrigation decisions were taken by EML's Farm Manager Mr Graham Caspell;

2) Irrigation Test Regime 1 (ITR1) where average soil matric potential (soil ψ_m) was maintained above -60 kPa during Stages I and II, and above -200 kPa during Stage III and post-harvest;

3) Irrigation Test Regime 2 (ITR2) where average soil ψ_m was maintained above -60 kPa during Stages I and II; during Stage III and post-harvest, irrigation was withheld until leaf physiological responses were detected. Irrigation was then applied to return soil to field capacity throughout the profile and thereafter, irrigation was applied when the average Ψ_m

reached -200 kPa. The duration of irrigation events was adjusted to ensure that the volume of water and fertilisers draining past the rooting zone was minimised.

A completely randomised block design was used with eight blocks (8 x 3 = 24 trees in total for each variety), each experimental tree within a row was separated by a guard tree. Irrigation was applied to the three irrigation treatments for each variety using separate irrigation lines. The frequency and duration of irrigation events to each was adjusted using Galcon irrigation controllers.

Measurement of soil matric potential and volumetric soil moisture content

Soil matric potential in each of the three treatments was monitored hourly from 12 March to 4 September 2015, using MPS2 sensors (Decagon Devices Ltd), inserted at depths of 20, 40 and 60 cm to ensure that changes in average soil ψ_m throughout the rooting zone were measured. The sensors were positioned 25 cm away from the North side of an experimental tree trunk and emitter. In each cultivar, MPS2 sensors were placed in three experimental plots for the CC and each DI treatment. Data loggers were downloaded daily and the average soil ψ_m over 60 cm soil depth for each treatment was calculated. To monitor the frequency, duration and volume of irrigation events, three ECRN rain gauges connected to EM50 data loggers were positioned directly below individual emitters within the CC and DI treatments of both cultivars and downloaded weekly.

Commercial irrigation regime

Irrigation scheduling to the CC trees was decided by EMR's Farm Manager. Fertigation was applied for 1-3 h per day from 6 May to 25 August 2015; the duration of each event was determined by the Farm Manager.

Irrigation scheduling in the DI treatments

The rate of soil drying within the rooting zone depended on daily evaporative demand and the stage of fruit development. The average soil ψ_m within the top 60 cm of soil was monitored continuously via telemetry and changes in these values dictated the frequency of irrigation events. The duration of each irrigation event was adjusted to ensure that the soil in the rooting zone returned to field capacity and ranged from 1-3 h during the growing season.

To ensure that crop yield was not affected by soil drying in the early stages of fruit development (stages I and II), irrigation was applied to maintain the average soil ψ_m above -60 kPa during this period in both the ITR1 and ITR2 treatments. At growth stage III, the lower set point of -200 kPa was used to trigger irrigation for the rest of the season in ITR1. In

ITR2, no irrigation was applied until significant differences in leaf or fruit morphological and/or physiological parameters were detected. The soil was then returned to field capacity. For the remainder of the season, irrigation was applied when the average soil ψ_m reached -200 kPa. Irrigation was ended in all treatments at the end of August 2015.

Physiological measurements

Tree physiological measurements were made on CC and ITR1 trees when the average soil ψ_m reached -200 kPa, just prior to an irrigation event, to determine if there were statistically significant differences in physiological responses at this soil ψ_m. In 2014, no significant physiological effects at this soil ψ_m were detected; however, physiological responses are also influenced by crop load and environmental conditions at the time of measurement, which vary from year to year. Measurements were first made on CC and ITR2 trees when the average soil ψ_m in the ITR2 treatment reached -250 kPa and were repeated at increasingly negative values to determine the average soil ψ_m at which leaf responses to limited soil water availability became significantly different from CC values. At this point, the ITR2 trees were perceiving and responding to a mild soil water deficit stress.

Midday stem water potential was measured using a Skye SKPM 1400 pressure chamber (Skye Instruments Ltd, UK). Mature, fully-expanded leaves were first enclosed in aluminium foil sleeves for 1.5 h prior to measurement. Leaves were excised, removed from the sleeves and placed, within 30 s, in the pressure chamber. The applied pneumatic pressure at which xylem sap first appeared at the cut surface of the petiole was recorded. Stomatal conductance (g_s) and rate of photosynthesis (*Pn*) of mature fully-expanded leaves was measured using a portable photosynthesis system (Li-Cor LI-6400XT).

Measurements of stem extension and fruit growth were made on all experimental trees at approximately weekly intervals, beginning on 6 May 2015 and continuing until harvest. Shoot extension rate (SER) was calculated by measuring two labelled shoots from different branches on each experimental tree. Fruit expansion rate (FER) was estimated by calculating the spherical volume of five fruit, each on a different fruit cluster on the same branch, determined from fruit length and width measurements made with digital callipers.

Fruit yield and quality

Fruit was harvested from ‘Kordia/Gisela5’ trees on 1 July 2015 and from ‘Merchant/Gisela5’ trees on 26 June 2015. Assessments of marketable yield, waste and fruit quality measurements were carried out as described above for Experiment 1.

Statistical Analysis

Statistical analyses were carried out using GenStat 13th Edition (VSN International Ltd). For each cultivar, analysis of variance (ANOVA) tests were carried out and least significant difference (LSD) values for $p<0.05$ were calculated to determine whether differences between the treatments were statistically significant.

Results

Effects of soil water deficits on return bloom, yields and quality (Experiment 1)

The DI treatments applied during growth stages I, II and III in 2014 had no statistically significant effects on return bloom in either variety in 2015 (Tables 1&2), with approximately 2,000 flower buds counted on each tree. Moreover, the DI treatments applied in 2014 did not affect Class 1 yield or fruit size in either variety in 2015 (Tables 1&2).

The most significant soil drying imposed in 2014 was during the post-harvest phase (DD3) and published work showed that fruit yields and quality could be reduced in the subsequent cropping year following post-harvest water stress applied to control vegetative vigour (see Discussion). However, Class 1 yields and individual fruit fresh weights of both 'Kordia/Gisela5' and 'Merchant/Gisela5' were unaffected by the DD3 treatments applied in the previous season. In 'Kordia/Gisela5', 5.6 Kg of fruit per tree was harvested from trees under the DD3 treatment, compared to 3.3 Kg per tree in the CC, but differences were not statistically significant due to high tree-to-tree variability. In 'Merchant/Gisela5', 8.9 Kg of fruit per tree was harvested from trees in the DD3 treatment, compared to 7.8 Kg in the CC, but again, these differences were not statistically significant. There were no effects of the previous season's treatments on SSC, firmness or size distribution in fruit harvested from 'Kordia/Gisela5' or 'Merchant/Gisela5' (Tables 3&4).

Table 1. Effects of the five irrigation treatments applied in 2014 on 'Kordia/Gisela5' return bloom and yield components at 2015 harvest.

2014 Treatment	Number of flower clusters	Marketable yield weight (Kg)	Average individual fruit weight (g)
CC	1916	3.32	12.03
DD1	1951	5.24	11.83
DD2	1920	5.92	11.60
DD3	2097	5.60	12.24
DD4	2352	3.86	12.02
P-prob	n.s	n.s	n.s
LSD	663.5	3.122	0.782

Table 2. Effects of the five irrigation treatments applied in 2014 on 'Merchant/Gisela5' return bloom and yield components at 2015 harvest.

2014 Treatment	Number of flower clusters	Marketable yield weight (Kg)	Average individual fruit weight (g)
CC	2634	7.81	10.97
DD1	1961	7.14	10.69
DD2	1940	7.78	10.66
DD3	2290	8.85	10.64
DD4	2045	7.45	10.64
P-prob	n.s	n.s	n.s
LSD	972.3	2.46	0.90

Effects of irrigation set points on marketable yields and quality (Experiment 2)

Effects of irrigation treatments on soil matric potential

Irrigation to the 'Kordia/Gisela5' and 'Merchant/Gisela5' trees under the CC treatment was scheduled by the Farm Manager, generally average soil ψ_m was maintained above -40 kPa (Figure 1 A&B). On two occasions, the average soil ψ_m under 'Kordia/Gisela5' trees fell below -40 kPa but it was returned to field capacity as the farm manager started to increase the length of irrigation events as the season progressed. In the ITR1 and ITR2 treatments, average ψ_m was maintained above -60 kPa during growth stage I and II in both cultivars (Figure 1 A&B). Changes in matric potential at the 20, 40 and 60 cm depths for each treatment and each variety are shown in Figures 2 and 3.

Table 3. Effects of the five irrigation treatments applied in 2014 on 'Kordia/Gisela5' fruit quality components at 2015 harvest.

Treatment	SSC	Firmness (g/mm))	Number of fruit from 50 fruit sample in each size category (mm)				
			24	26	28	30	32
CC	16.86	255.4	0.0	3.2	15.5	21.8	7.5
DD1	17.73	256.7	0.0	7.2	29.8	13.0	0.2
DD2	16.81	252.3	0.2	10.2	24.2	11.5	4.0
DD3	18.27	242.3	0.2	6.5	25.3	17.5	0.5
DD4	17.45	253.5	0.3	5.3	23.0	20.2	1.2
P-prob	n.s	n.s	n.s.	n.s.	n.s.	n.s.	n.s.
LSD	1.74	23.2	0.4	8.7	12.8	16.3	6.9

Table 4. Effects of the five irrigation treatments applied in 2014 on 'Merchant/Gisela5' fruit quality components at 2015 harvest.

Treatment	SSC	Firmness (g/mm))	Number of fruit from 50 fruit sample in each size category (mm)				
			24	26	28	30	32
CC	16.97	187.2	0.0	2.7	15.7	27.8	4.0
DD1	17.29	178.8	0.0	2.8	13.3	26.3	7.7
DD2	18.09	189.3	0.3	6.3	13.8	19.5	10.5
DD3	17.07	183.6	0.3	2.2	20.2	25.8	1.5
DD4	17.07	187.0	0.2	5.8	15.0	19.8	9.2
P-prob	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD	1.15	17.8	0.6	5.3	8.3	7.5	7.8

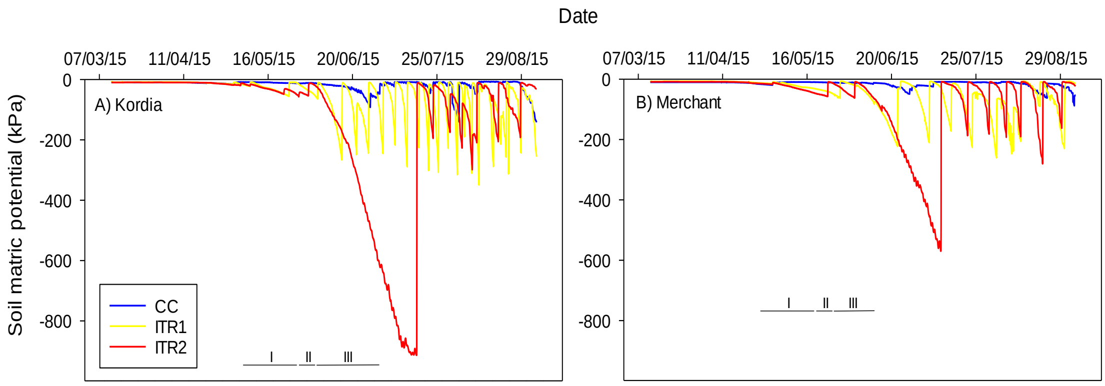

Figure 1. Changes in soil matric potential averaged over the top 60 cm of soil in each of the three irrigation treatments applied to A) 'Kordia/Gisela 5' and B) 'Merchant/Gisela 5' trees in 2015.

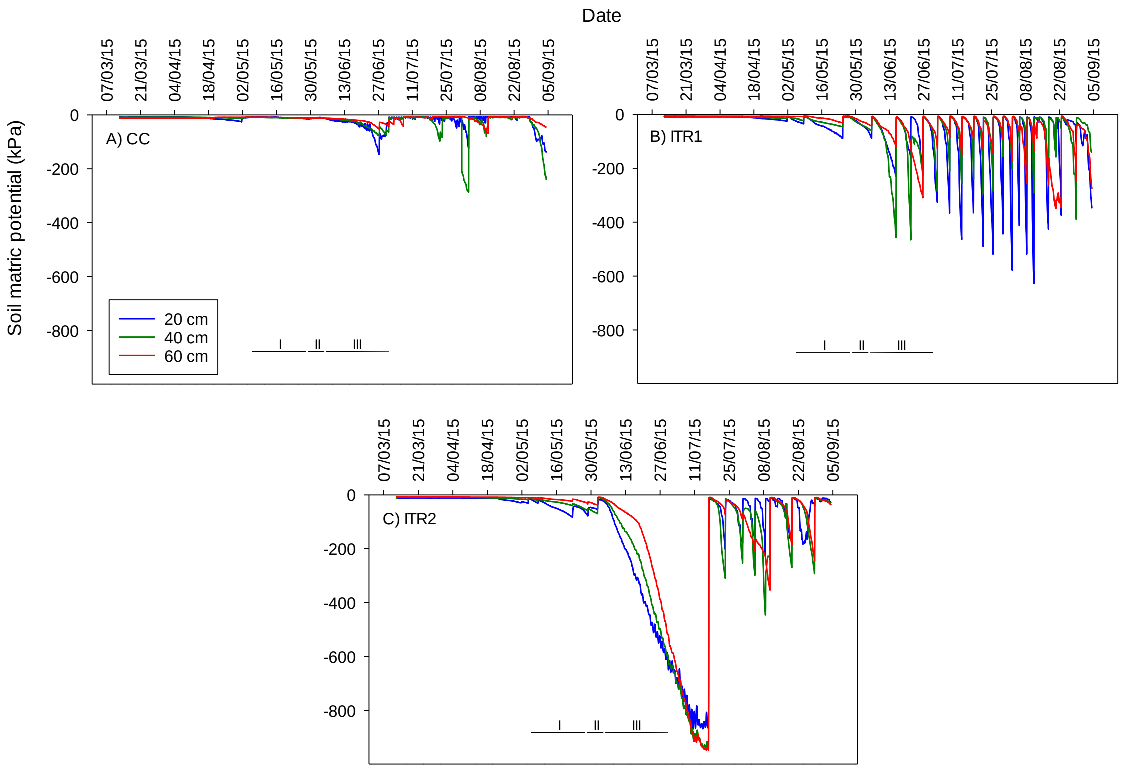

Figure 2. Changes in soil matric potential at 20, 40 and 60 cm depth in ‘Kordia/Gisela5’ trees under the three irrigation treatments; A) Commercial Control. B) Irrigation Test Regime 1 and C) Irrigation Test Regime 2.

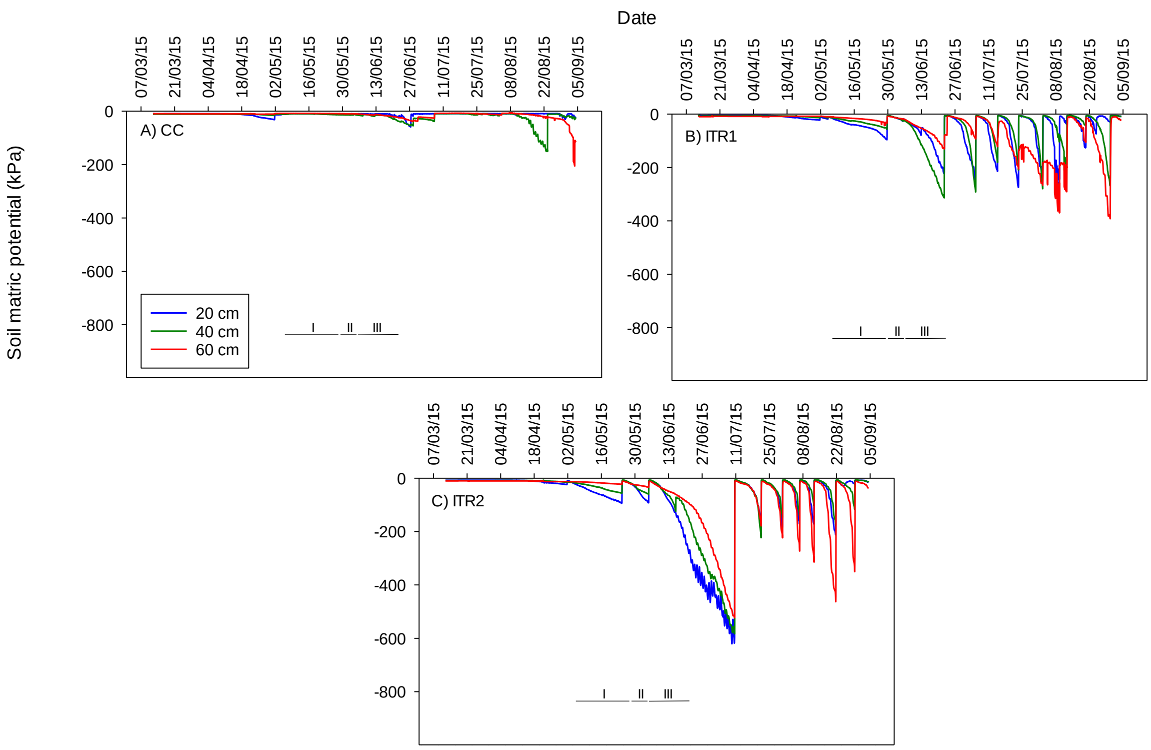

Figure 3. Changes in soil matric potential at 20, 40 and 60 cm depth in ‘Merchant/Gisela5’ trees under the three irrigation treatments; A) Commercial Control. B) Irrigation Test Regime 1 and C) Irrigation Test Regime 2.

Stage III of fruit development began on 4 and 8 June 2015 in 'Kordia/Gisela5' and 'Merchant/Gisela5', respectively. Subsequent irrigation events to ITR1 trees were triggered at -200 kPa and on the majority of occasions, irrigation was applied when average soil ψ_m reached -200 to -250 KPa. During Stage III, three irrigation events were applied to 'Kordia/Gisela5' under the ITR1 treatment, and one event was applied to 'Merchant/Gisela5'.

During the post-harvest phase, 15 irrigation events were applied to 'Kordia/Gisela5' trees and eight to 'Merchant/Gisela5'. The soil ψ_m in 'Kordia/Gisela5' ITR2 trees fell to -900 kPa before statistically significant declines in all leaf physiological parameters were detected on 16 July 2015 (see below). At this point, the soil in the top 60 cm was returned to field capacity, and six further irrigation events were applied until the end of August 2015. In 'Merchant/Gisela5', the soil ψ_m at which the leaf physiological parameters were detected was -60 kPa on 10 July 2015, after which the trees were irrigated to bring soil back to field capacity. A further six irrigation events were applied until the end of August 2015. In both cultivars, the lowest average soil ψ_m at which all physiological responses measured differed significantly from CC values occurred during the post-harvest phase. During the pre-harvest phase, changes in some of the physiological parameters were detected at average soil ψ_m of -600 kPa and -358 kPa in 'Kordia/Gisela5' and 'Merchant/Gisela5', respectively, indicating that trees were perceiving a mild but transient soil water deficit stress.

Leaf Physiological Parameters

Leaf physiological responses were measured to assess whether trees were experiencing soil water deficit stress under the ITR1 and ITR2 treatments. On one occasion during the post-harvest period, ψ_{ms} of 'Kordia/Gisela5' trees under the ITR1 treatment measured at the irrigation set point of -200 kPa, were significantly reduced compared to CC values (Figure 4A); however, *Pn* and g_s were unaffected by the ITR1 treatment (Figure 4 B&C), indicating that trees were experiencing a mild but transient soil water deficit stress. In ITR2, ψ_{ms} was reduced significantly, compared to the CC treatment when measured on 29 June 2015, one day prior to harvest (Figure 5A), but was not affected 4 days earlier. Photosynthesis was also reduced significantly in the ITR2 treatment during this time (Figure 5B), when average soil ψ_m ranged from -430 to -599 kPa in the ITR2 treatment. Stomatal conductance was reduced significantly at an average soil ψ_m of -900 kPa which occurred during the post-harvest stage (Figure 5C).

In 'Merchant/Gisela5' trees under the ITR1 treatment, reductions in ψ_{ms} were detected on one occasion (14/07/15), indicating that the trees were experiencing a mild water deficit stress at an average soil ψ_m of -200 kPa (Figure 6A). In the ITR2 treatment, physiological responses were triggered at average soil ψ_m between -475 and -550 kPa (Figures 6&7), but again, these responses occurred post-harvest. At harvest, the average soil ψ_m was -250 kPa and no physiological responses were detected in the ITR2 trees at this point.

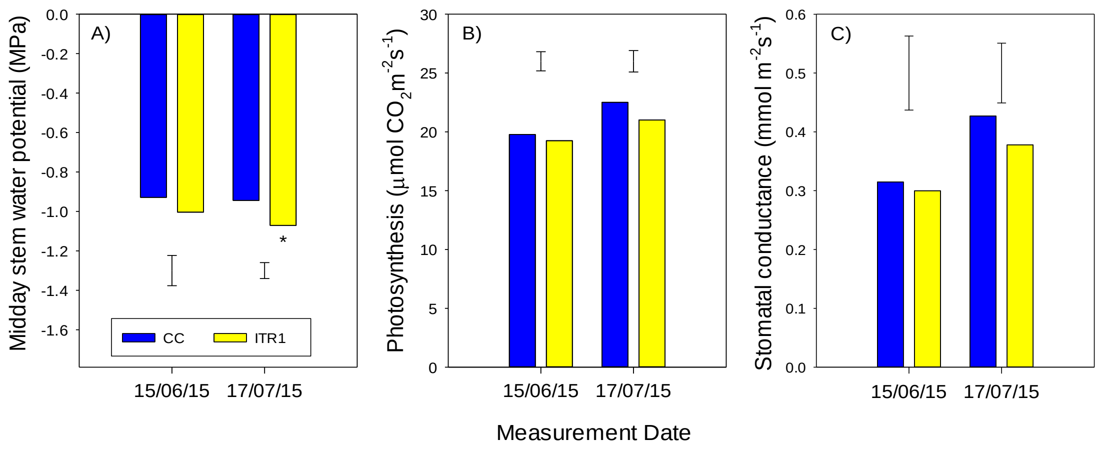

Figure 4. The effects of the ITR1 irrigation treatment on A) midday stem water potentials, B) Photosynthesis and C) stomatal conductance in 'Kordia/Gisela 5' trees. Results are means of eight replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

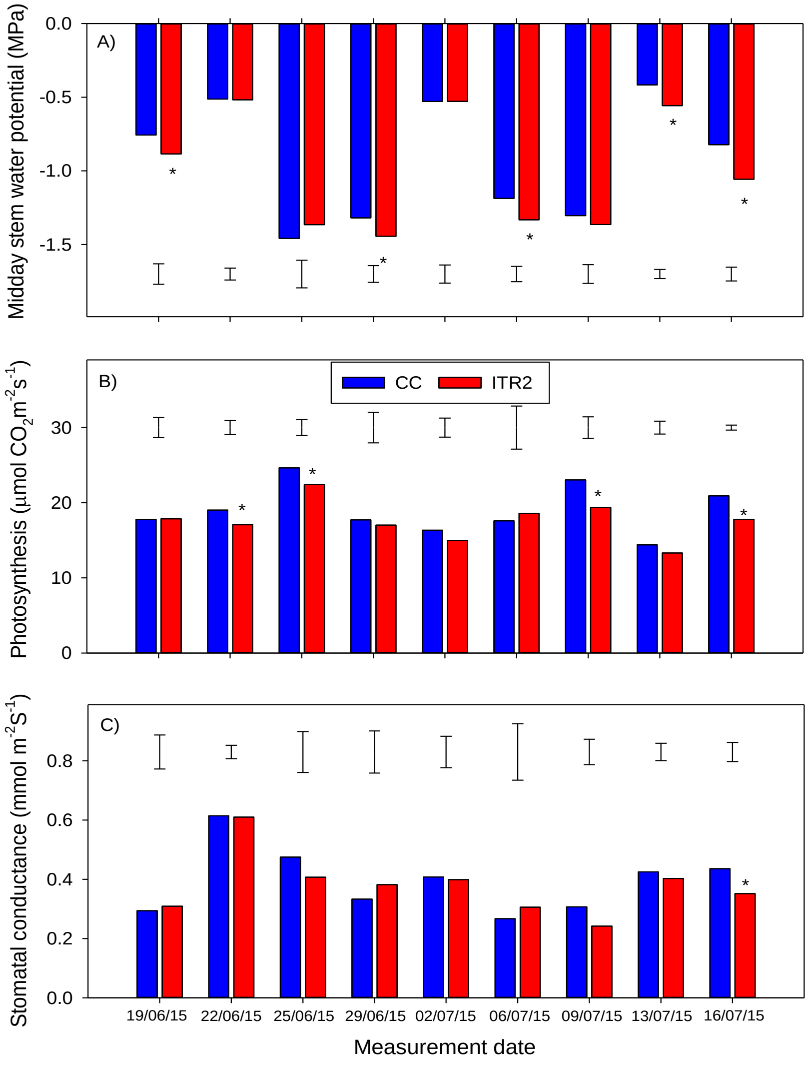

Figure 5. The effects of the ITR2 irrigation treatment on A) midday stem water potentials, B) Photosynthesis and C) stomatal conductance in 'Kordia/Gisela 5' trees. Results are means of eight replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

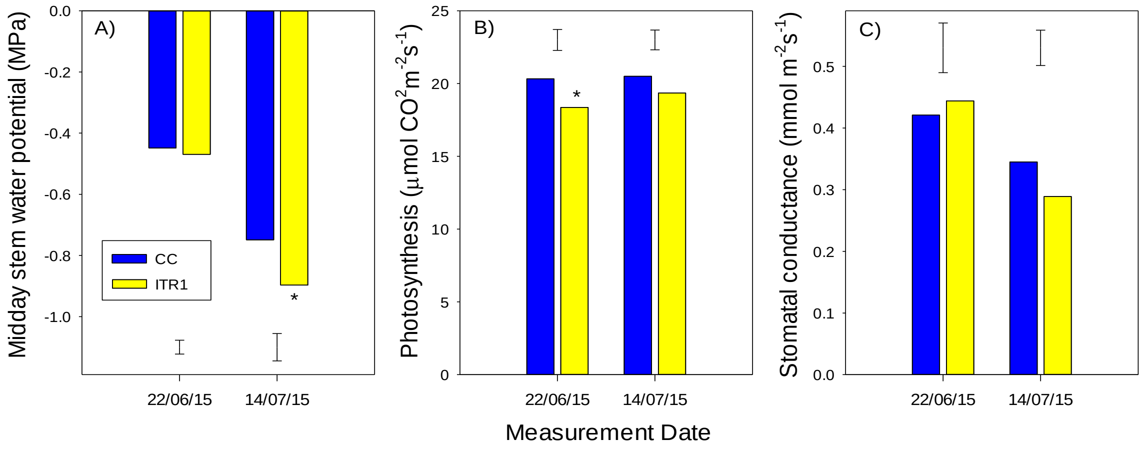

Figure 6. The effects of the ITR1 irrigation treatment on A) midday stem water potentials, B) Photosynthesis and C) stomatal conductance in 'Merchant/Gisela 5' trees. Results are means of eight replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

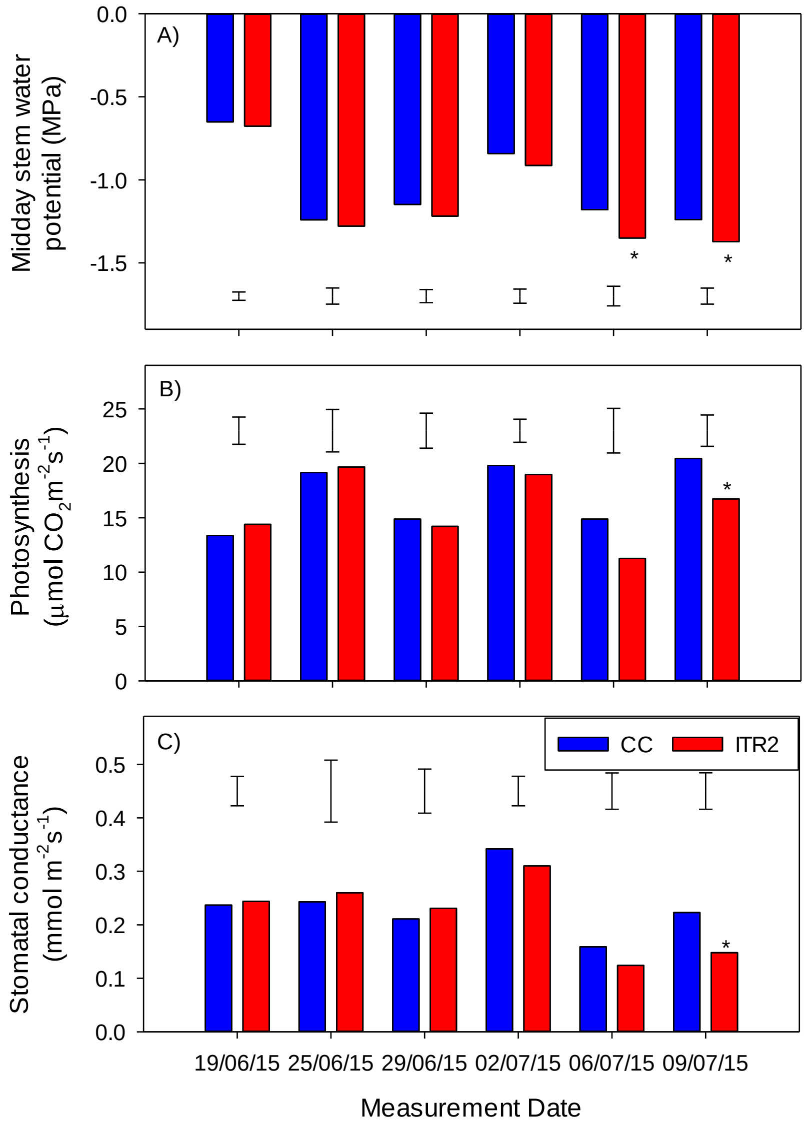

Figure 7. The effects of the ITR2 irrigation treatment on A) midday stem water potentials, B) Photosynthesis and C) stomatal conductance in 'Merchant/Gisela 5' trees. Results are means of eight replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

Fruit and Shoot Growth

In both ‘Kordia/Gisela5’ and ‘Merchant/Gisela5’, fruit extension rate (FER) and cumulative fruit growth (Figure 8) were not significantly affected by the irrigation treatments, with the exception of fruit diameter in ‘Kordia/Gisela5’ under the ITR2 treatment on 30 June 2015 at an average soil ψ_m -600k Pa and (data not shown). Shoot extension rate and cumulative shoot growth under the ITR1 and ITR2 treatments were not significantly different from CC values in either variety (data not shown).

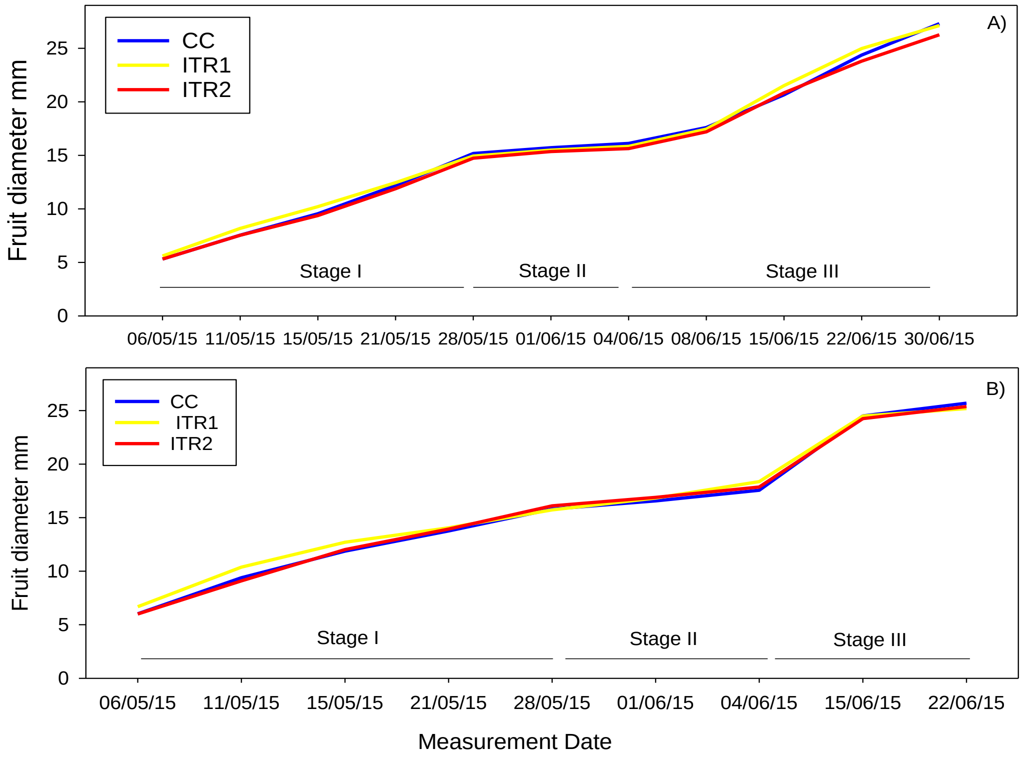

Figure 8. The effects of the three irrigation treatments fruit diameter in A) ‘Kordia/Gisela5’ and B) ‘Merchant/Gisela5’ trees. Results are means of eight replicate trees.

Fruit yield and quality at harvest

Class 1 yields of ‘Kordia/Gisela5’ were unaffected by the ITR1 and ITR2 treatments (Table 5), despite evidence of mild water deficit stress pre-harvest. However, individual fruit weight was reduced significantly in the ITR1 (11.9 g) and ITR2 (11.8 g) treatments, when compared to the CC (12.6 g) although there were no differences in fruit size distribution (Table 6). There were no differences in fruit firmness or SSC between the treatments (data not shown).

In ‘Merchant/Gisela5’, there were no significant treatment differences in Class 1 yields, which averaged 6.9, 5.9 and 5.7 kg per tree under the CC, ITR1 and ITR2 treatments respectively (Table 5). Individual fruit weight was not significantly different between treatments with values of 11.0, 11.1 and 10.8 g for the CC, ITR1 and ITR2 treatments respectively. There were no differences in fruit firmness or SSC between the treatments

(Tables 6&7).

Table 5. Effects of the three irrigation treatments on 'Kordia/Gisela5' and 'Merchant/Gisela5' on Class 1 yield and average fruit weight at harvest in 2015.

	'Kordia/Gisela5'		'Merchant/Gisela5'	
Treatment	Marketable yield weight (Kg)	Average individual fruit weight (g)	Marketable yield weight (Kg)	Average individual fruit weight (g)
CC	6.73	12.6	6.86	11.0
ITR1	7.04	11.9	5.90	11.1
ITR2	8.64	11.8	5.71	10.8
P-prob	n.s	*	n.s	n.s
LSD	3.04	0.55	2.19	0.75

Table 6. Effects of the three irrigation treatments on 'Kordia' fruit quality components at harvest.

Treatment	SSC	Firmness (g/mm)	Number of fruit from 50 fruit sample in each size category (mm)					
			22	24	26	28	30	32
CC	18.8	235.4	0.0	0.4	6.2	27.0	15.9	0.5
ITR1	19.0	229.1	0.0	0.8	10.8	31.1	7.4	0.0
ITR2	19.0	234.4	0.0	1.2	9.4	32.1	7.2	0.1
P-prob	n.s	n.s		n.s.	n.s.	n.s.	n.s.	n.s.
LSD	1.11	17.89	*	1.13	6.20	7.00	8.39	0.49

Table 7. Effects of the three irrigation treatments on 'Merchant' fruit quality components at harvest.

Treatment	SSC	Firmness (g/mm)	Number of fruit from 50 fruit sample in each size category (mm)					
			22	24	26	28	30	32
CC	17.5	200.9	0.0	1.24	9.12	25.8	13.2	0.62
ITR1	18.0	217.8	0.25	2.00	13.12	22.6	10.7	1.25
ITR2	18.2	207.6	0.37	2.12	10.88	27.6	8.8	0.25
P-prob	n.s	n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD	1.02	16.81	0.48	1.61	5.10	6.57	6.96	1.26

Volumes of irrigation water applied and water productivity values

The total volume of irrigation water applied during the 2015 season to each ‘Kordia/Gisela5’ tree was 1,622, 450 and 244 L in the CC, ITR1 and ITR2 treatments, respectively (Table 7). The ITR1 and ITR2 trees received 72% and 85% less water than those in the CC treatment, respectively. In ‘Merchant/Gisela5’, the total volume of irrigation water applied was 1,754, 209 and 188 L for the CC, ITR1 and ITR2 trees, respectively (Table 8). Water savings of 88% and 89% were achieved in the ITR treatments, compared to the CC.

The WP value of the CC treatment for ‘Kordia/Gisela5’ was calculated to be 241 i.e. 241 L irrigation water was applied to achieve each Kg of Grade 1 fruit (Table 9); this value is considerably higher than the average value of 66 reported by growers interviewed as part of EMR’s WATERR project. A similarly high WP value of 256 was achieved for the CC ‘Merchant/Gisela5’ trees, and these results suggests that irrigation scheduling to this orchard could be improved considerably to ensure that water and fertilisers are used more efficiently. In the ITR1 treatments, WP values of 64 and 35 were achieved for the two varieties, and in the ITR2 treatments, WP values were 28 and 33 (Table 8). These results indicate that significant improvements in irrigation scheduling and water use efficiency in the intensive production of covered sweet cherry crops can be made without compromising marketable yields, fruit quality or return bloom.

Table 8. Volumes of irrigation water applied to 'Kordia/Giseal5' and 'Merchant/Gisela5' trees under the three irrigation treatments.

Cultivar	Volume of irrigation applied per tree (L)		
	CC	ITR 1	ITR 2
'Kordia/Giseal5'	1622	451	245
'Merchant/Gisela5'	1754	209	188

Table 9. Water productivity, litres of water used for each Kg of fruit, for 'Kordia/Giseal5' and 'Merchant/Gisela5' trees under the three irrigation treatments.

Cultivar	Water Productivity (L / Kg)		
	CC	ITR 1	ITR 2
'Kordia/Giseal5'	241	64	28
'Merchant/Gisela5'	256	35	33

Discussion

In the absence of irrigation 'best practice' guidelines, UK top fruit growers often maintain the soil at or near to field capacity throughout the cropping season to ensure that unplanned soil moisture deficits don't reduce Grade 1 yields or fruit quality. However, this approach can lead to excessive shoot growth and altered dry matter partitioning and significant leaching of water and fertilisers, and any rain that falls within the cropping season is not utilised effectively. A key output of our research is the identification of the range of soil water availabilities over which Grade 1 yields, fruit quality and storage potential are optimised in two commercial apple varieties. For apple, results over two cropping seasons with 'Gala/M.9' and 'Braeburn/M.9' using the AWD approach showed that it is not necessary to apply frequent irrigation events to maintain the soil near to field capacity to deliver good commercial yields. Using AWD with an irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) from 6 weeks after full bloom until harvest will optimise both on-farm water use efficiency and crop productivity in 'Gala/M.9' and 'Braeburn/M9'. In the absence of research proving otherwise, growers should continue to follow current recommendations to maintain soil at or near to field capacity from anthesis until 6 weeks after full bloom.

In EMR's recently completed ERDF-funded WATERR project, in which 16 top fruit growers were interviewed, the reported average volume of irrigation water applied in 2011-2013 was 197 m^3 per ha, with a range of 22-860. Average yields of 25 tonnes per ha were achieved, with a range of 13-30. Although there are a number of factors that impact on these figures, such as soil type, planting density etc., the range of values in each category illustrate the variability in production efficiency in commercial top fruit production. The efficiency with which irrigation water is used to produce marketable yield can be expressed by calculating the Water Productivity (WP) value; a lower value indicates a more productive use of water. The average WP value over 2011-2013 was 7 m^3 per tonne, with a range of 3-14. This range clearly illustrates the potential to improve the productivity with which irrigation water is used in the tree fruit sector. In our work, the WP value achieved for 'Gala/M.9' and 'Braeburn/M.9' under the ITR1 treatment in 2014 was 1.4, compared to 26 for the CC regime. The high WP value under the CC regime suggests that more accurate irrigation scheduling in the orchard at EMR would deliver significant water savings.

The combination of evaporative demand and rainfall in any season, combined with differences in canopy areas and cropping load will obviously influence how much irrigation water needs to be applied to achieve good fruit size in any given orchard. In some wetter years, irrigation may not be needed. In this project, the NI treatment was imposed to test whether irrigation was necessary to ensure good marketable yields, high fruit quality and consistency of cropping in high intensity apple production. In both 2013 and 2104, when production relied entirely on rainfall, there were no significant treatment effects on individual fruit fresh weight or Grade 1 yields compared to the CC and ITR treatments, although the trend was for smaller fruit from the NI treatments. In 2014, the accumulated evapotranspiration over the season in the Concept Pear Orchard at EMR was 446 mm, and 397 mm of rainfall fell in the 'Gala/M.9' and 'Braeburn/M.9' orchard between April and October (see Appendices 1&2).. By 8 August 2014, 222 mm of rainfall had fallen, and accumulated evapotranspiration was 342 mm, resulting in an estimated soil moisture deficit of 80 mm; average soil ψ_m in the top 60 cm of soil at this time was -310 kPa. Our results suggest that yields and quality of both 'Gala' and Braeburn' were not affected by this degree of soil moisture deficit and so irrigating to maintain soil near to field capacity is not necessary.

In both 2013 and 2014, rainfall during the cropping season limited the extent of soil drying that was imposed in the NI treatment, and the withholding of irrigation in a drier year would presumably have limited fruit size and Grade 1 yields. Most tree fruit growers now consider drip irrigation to be essential to avoid soil moisture deficits that limit fruit expansion, and to ensure the consistency of yields of Grade I fruit in successive cropping seasons. As one tree fruit grower put it: "The main purpose of irrigation in tree fruit is to meet supermarket requirements for produce uniformity. My irrigation system paid for itself within one year."

The project results show that significant water savings can be achieved if irrigation is scheduled using AWD with the lower irrigation set points developed at EMR. Further work is now needed to test this water-saving irrigation strategy on commercial 'Gala' and 'Braeburn' orchards. Technologies being developed in on-going Innovate UK projects at EMR including LIDAR, PomeVision, GP2-based precision irrigation and thermal and hyperspectral imaging could be used in tandem with AWD to monitor crop health and performance under these low-input growing systems. These technologies will also enable us to test the potential to use deficit irrigation to further improve water use efficiency, fruit dry matter content and storage potential in commercial orchards.

The area planted to sweet cherry in the UK has risen by 77% in the last 10 years to 688 ha in 2015, and the majority of production is in areas where there is already high demand for limited supplies of freshwater. Some growers have taken the decision not to cover their crops and so these will benefit from seasonal rainfall, but the overall result of the continued planting of sweet cherry orchards will be an increased demand for irrigation water during the summer months. Responses from the sweet cherry growers interviewed in the WATERR project showed that the average volume of irrigation water applied per ha was 315 m^3, with a range of 104 – 771 m^3 per ha. The average WP value was 66, with a range of 38 – 94. These data suggest that there is scope to improve on-farm water use efficiencies without reducing marketable yields or fruit quality, but new guidelines are needed to help growers to achieve this.

Whilst irrigation is needed to ensure good fruit size and quality in covered sweet cherry crops, excessive irrigation applied to try to meet retailer specifications for fruit size resulted in fruit rupturing on the way to the pack house at one grower site in 2013. The aim of our work was to develop irrigation scheduling strategies that have the potential to deliver water savings in high intensity sweet cherry production, without reducing Class 1 yields or fruit quality. Our results show that significant improvements in water use efficiency can be achieved without reducing Class 1 yields of 'Kordia/Gisela 5' and 'Merchant/Gisela 5' if AWD is used with lower irrigation set points of -60 and -200 kPa during Stages I-2, and III respectively. However, average fruit weight of 'Kordia/Gisela5' at harvest was significantly reduced under the ITR1 and ITR2 treatments, presumably due to a slower rate of fruit expansion in the final week before harvest (see Figure 8). Soil matric potentials at this time were between -13 and -244 kPa in the ITR1 treatment, and -300 and -500 kPa in the ITR2 treatment. Average soil ψ_m in the CC treatment was between -34 and -74 kPa during this period. Despite these differences in soil ψ_m, there were no significant differences in ψ_{ms} between the CC and the ITR1 treatment at this time, so the lower individual fruit weight in the ITR1 treatment was presumably due to differences in crop load, (see Table 5), rather than to limited soil water availability. In the ITR2 treatment, ψ_{ms} was reduced significantly on the day before harvest, compared to CC values. However, rates of fruit expansion began to slow before changes in ψ_{ms} were detected, and again, differences in crop load are the most likely explanation for the lower individual fruit fresh weights in the ITR2 treatment.

When using AWD, growers should aim to maintain soil around -10 to -200 kPa to optimise Class 1 yields in 'Kordia, and it is important to return the soil to field capacity throughout the rooting zone after each irrigation event. Care should be taken to avoid over-irrigation just prior to harvest time to avoid potential problems with the skin of fruit rupturing.

Results from our experiments in 2014 and 2015 indicate that Class 1 fruit number in 'Merchant/Gisela5' can be sensitive to relatively mild soil water deficits during fruit growth stage 1. The extent to which soil water availability affects Class 1 yields will vary depending upon rootstock, scion variety, evaporative demand, crop load, canopy area and other interacting factors but the results from this project suggest that ineffective irrigation scheduling during the different fruit growth stages could potentially reduce Class 1 yields and fruit size. In addition to more information about the relative sensitivities of different cultivars, effective irrigation scheduling tools are needed to help growers to maintain soil water availability within the optimum range. Two thirds of tree fruit growers use tools to monitor and/or schedule irrigation but the range of WP values achieved by the growers suggest that these tools could be used more effectively.

In both the apple and sweet cherry experiments, we have measured changes in soil ψ_m at 20, 40 and 60 cm, and used a calculated average soil ψ_m to schedule irrigation. With this approach, it is important to determine if water is being extracted from deeper soil layers, as this would lead to an over estimation of the tolerance of each variety to drying soil in the top 60 cm. The soil ψ_m at 60 cm fell to -100 kPa in early August in 'Braeburn/M.9' trees, while at depths of 20 and 40 cm, values of -1,000 and -180 kPa were reached, which indicates that the majority of the water used by the trees was extracted from the top 40 cm. Similar results and conclusions were obtained for 'Kordia/Gisela 5' and 'Merchant/Gisela5' in 2015.

In addition to the advanced irrigation scheduling and imaging technologies being developed in our on-going IUK projects referred to above, there is a need for a low cost, simple visual system that can be used by tree fruit growers to inform their irrigation decisions. The potential of the G-Dot system (Figure 9) to provide growers with an easy to interpret, visual cue on when and when not to irrigate has been tested at EMR and trialled on commercial grower sites by Earthcare Environmental Ltd. This entry-level tool combines a device for measuring the availability of water in soil around crop roots with an easy-to-read real-time display based on seven yellow dots (but with no data storage):

- seven yellow dots means that the soil is wet, i.e. at or near to field capacity
- six or fewer yellow dots means that the soil matric potential is decreasing i.e. the soil is drying down
- one or two yellow dots means the soil matric potential is approaching -100 kPa and is the trigger for an irrigation event

The G-Dot has a narrow range of measurement (-10 to -100 kPa) in comparison with the Decagon MPS-2 matric potential sensor (-10 to -500 kPa). The resolution is also less, with the driest category covering the range -60 to -100 kPa. In principle, the G-Dot should serve as a useful and inexpensive visual irrigation scheduling tool and feedback from sweet cherry growers in 2015 has been very positive. The G-Dot system now needs to be evaluated more widely.

Figure 9. The low-cost G-Dot system and Watermark matric potential sensor responds to declining soil matric potential in the range from -10 to -100 kPa using a system of lights (7 lights indicate field capacity, no lights indicates a soil matric potential of -100 kPa.

There are alternatives to using measures of soil water content or availability to schedule irrigation. Overseas, irrigation is scheduled to commercial orchards using a variety of different approaches including estimates of evapotranspiration (ET) used in combination with generic crop co-efficients (Marsal *et al*., 2009), remote sensing of leaf temperatures using thermal imaging and measurements of trunk diameter fluctuations (TDF) and ψ_{ms} (Livellara et al., 2010). Each of these approaches has its merits and drawbacks, but the latter approach measures the trees' response to soil water availability directly, and is used to ensure that sufficient irrigation is applied in hotter, drier countries to avoid limiting fruit expansion rates under high evaporative demands. For the UK tree fruit sector, a combination of irrigation scheduling approaches in which changes in soil water availability are integrated with evaporative demand will help to inform on-farm irrigation decision making. The Internet of Things (IOT) offers the opportunity to develop an array of low cost disposable sensors that measure, monitor and integrate a range of environmental metrics that influence crop yields and quality.

Conclusions

Apple

- 'Gala/M.9' trees under the ITR were irrigated only twice during the growing season, but no physiological responses to drying soil were detected and yields and number of Class 1 fruit were similar to CC values.
- In the NI treatment, the average soil matric potential fell to -310 kPa during August, and although this resulted in significant reductions in midday stem water potentials and rates of photosynthesis, 'Gala/M.9' Class 1 yield and number were not affected.

- 'Braeburn/M.9' trees under the ITR treatment received only one irrigation event because heavy rainfall in August returned the soil to field capacity just before the irrigation set point was reached. The number and yield of 'Braeburn' Class 1 fruit were similar to those in the CC treatment.
- Significant reductions in midday stem water potential were detected in the NI treatment but the number and yield of Class 1 'Braeburn' fruit were not affected.
- Results suggest that it is not necessary to apply frequent irrigation events to maintain the soil near to field capacity to deliver good commercial yields in 'Gala' and 'Braeburn'. This approach will increase leaching of N and other nutrients past the rooting zone
- Trees of both varieties under the NI treatment received 397 mm rainfall between 12 April and 26 October 2015. Potential evapotranspiration during this time was 446 mm

Sweet Cherry

- In 'Kordia/Gisela 5', average soil matric potentials fell to -65, -218, -581 and -900 kPa during stages I, II, III and post-harvest, respectively. Rates of photosynthesis were similar irrespective of treatment and there were no significant treatment effects on 'Kordia' Class 1 yields, which ranged from 1.6 to 3.2 Kg per tree.
- In the post-harvest treatment, midday stem water potentials were significantly lowered once the average soil matric potentials fell beyond -350 kPa, but this did not affect return bloom, Class 1 yields and fruit quality in the subsequent cropping year.
- In 'Merchant/Gisela 5', average soil matric potentials fell to -115, -22, -332 and -925 kPa during the four deficit irrigation treatments. The mild soil drying imposed during Stage 1 significantly reduced both yield (2 Kg vs 3 Kg) and number (172 vs 285) of Class 1 fruit per tree, compared to the CC treatment.
- In 'Merchant/Gisela5', mild soil drying during fruit growth Stage 1 will significantly reduce both yield and number of Class 1 fruit per tree
- Significant saving of water can be achieved without reducing Class 1 yields of 'Kordia/Gisela5' and 'Merchant/Gisela5' if AWD is used with lower irrigation set points of -60 and -200 kPa during Stages I-II, and III respectively.

Knowledge Exchange and Technology Transfer activities during Year 3

- 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
- Presentation at the Delta-T "SPAC" conference, 13 October 2015, Rothamsted Research, Harpenden
- A summary of the aims, objectives and results was prepared for the 2016 Tree Fruit Review
- Project aims, objectives and deliverables were presented at the AHDB Tree Fruit Day, 23 February 2016

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Appendix 1. Environmental metrics recorded by the Agrii weather station in the Concept Pear Orchard at EMR during the 2014 cropping season.

Date	ET_o (mm)	Air temperature (°C)		Average light intensity (W/m²)	RH (%)	Rainfall (mm)
		Maximum	Minimum			
01/04/2014	2.57	20.3	4.3	187.8	93.5	0
02/04/2014	1.71	19.7	6.9	123.2	94	0
03/04/2014	1.61	18.8	8.3	113.8	94.6	0
04/04/2014	1.06	14.9	6.8	70.5	94.9	0
05/04/2014	1.56	16.6	3.7	132.2	95.2	0
06/04/2014	0.89	16.1	12.4	66.2	95.2	1.8
07/04/2014	0.46	14.2	7.4	40.5	95.8	14.2
08/04/2014	1.97	13.4	5.6	141.9	96	0
09/04/2014	2.45	17.4	2	186.9	96.2	0
10/04/2014	1.69	17.4	2.9	124	96.3	0
11/04/2014	1.48	16.1	4.9	105.9	96.2	0
12/04/2014	1.95	15.7	4.7	134.9	96.3	0
13/04/2014	2.8	16.6	7.9	205.1	96.7	0
14/04/2014	2.56	15.5	3	196.6	96.8	0
15/04/2014	2.36	12.9	1	202.8	97	0
16/04/2014	2.75	15.7	0.1	217.4	97.1	0
17/04/2014	2.36	20	2.6	154.5	96.7	0
18/04/2014	1.94	13.5	5.6	156.4	97.2	0
19/04/2014	1.8	13.5	5.4	146	97.4	0
20/04/2014	0.41	12.7	5.2	36.7	97.1	8.4
21/04/2014	2.75	19.2	4.7	203	97.3	16.8
22/04/2014	1.56	17	8.6	111.8	97.6	11.6
23/04/2014	2.17	18.3	5.8	155.8	97.8	0
24/04/2014	1.49	17.1	9.3	107.6	98	0
25/04/2014	0.47	15.2	7.4	38	98	0
26/04/2014	1.55	15.5	7.2	113.6	98.1	3.4
27/04/2014	1.75	16	8.3	138.6	98.5	1
28/04/2014	1.64	16.4	7.4	120.2	98.7	0
29/04/2014	1.33	16.3	5.4	103	99	0.2
30/04/2014	2.29	20	6.5	158.4	98.6	0
01/05/2014	0.73	14.8	6.2	60.3	98	16.8
02/05/2014	0.66	12	3.7	52.4	96.5	0
03/05/2014	2.33	14.2	1.1	184.5	92.6	0
04/05/2014	2.68	17.3	0.3	200.4	86.2	0
05/05/2014	2.61	18.8	1.3	175.2	78.9	0
06/05/2014	2.8	19.6	9.1	186.5	73.5	0
07/05/2014	2.07	17	9.3	139.6	72.4	0.2
08/05/2014	0.7	14.7	10.7	56.1	70.6	3.2
09/05/2014	3.07	18.1	10.5	199	69.4	0
10/05/2014	2.16	17.5	9.9	164.1	68.3	2.8
11/05/2014	2.26	15.6	8.9	131.3	65	0
12/05/2014	2.01	16.1	8.1	135.3	64.3	0
13/05/2014	1.82	17.3	6.8	140.6	63.7	3.4
14/05/2014	2.8	19	5.5	194.1	62.3	0
15/05/2014	2.78	21	3.6	181.9	61	0

16/05/2014	3.28	21.7	4.3	209.3	58.1	0
17/05/2014	2.48	23.9	7.9	153.9	57.3	0
18/05/2014	3.54	23.8	8.4	215.2	54.3	0
19/05/2014	3.7	25.3	9.1	205.2	54	0
20/05/2014	2.23	21.9	11.9	139.7	52.9	0
21/05/2014	1.45	17.9	9.8	99.9	53.2	8
22/05/2014	1.97	17.8	11.8	144	52.7	4.4
23/05/2014	2.7	18.5	8.5	185	52.2	0
24/05/2014	1.57	16.3	8.5	125.4	52.2	10.6
25/05/2014	3.14	18.6	8.4	220	51.4	0
26/05/2014	1.1	17.6	9.7	81.4	48.1	9.8
27/05/2014	0.38	12.9	10.2	33.7	45.7	9.2
28/05/2014	0.51	14.8	9.9	43.7	46.2	1
29/05/2014	2.12	20.2	11.9	145.8	47.8	0
30/05/2014	2.04	16.7	7.2	147.6	46.7	0
31/05/2014	2.07	19.8	6.4	135	45.6	0
01/06/2014	2.17	21	10.5	134.8	44.6	0
02/06/2014	2.11	21.8	10.9	136.3	45	0.4
03/06/2014	2	20	11.7	139.2	46.1	0
04/06/2014	1.46	15.6	6.1	108.3	48.2	5.2
05/06/2014	3.04	20.2	6	199	53.2	0.6
06/06/2014	3.38	23.9	4.9	203.4	60.6	0
07/06/2014	2.98	24.5	11.2	186.7	62.2	1.2
08/06/2014	3.41	25.9	9.6	200.4	63.3	0
09/06/2014	2.55	25.7	12.8	155.6	65	0
10/06/2014	3.78	23.4	10.7	232.9	66.4	0
11/06/2014	2.78	23.1	9.6	172.2	68.4	0
12/06/2014	3.55	26	9.4	211.9	69.8	0
13/06/2014	2.67	25.6	9.7	156.5	70.7	0
14/06/2014	1.35	19.5	12.1	87.5	72.6	0
15/06/2014	1.53	18	12.1	96.8	74	0
16/06/2014	1.42	17.4	12.1	92.5	76.1	0
17/06/2014	3.07	20.7	11.3	204.6	80.4	0
18/06/2014	2.32	21.5	9.9	153.9	83.3	0
19/06/2014	1.55	22.9	7	99.5	84.1	0
20/06/2014	3.29	22.7	7	217.9	85.3	0
21/06/2014	3.37	25.1	8.4	207.4	86.4	0
22/06/2014	3.44	24.3	10.4	209.2	87.4	0
23/06/2014	2.61	25.8	9.2	152.7	89.2	0
24/06/2014	2.4	24.7	11.9	148.3	90	1.2
25/06/2014	3.04	20.8	9.6	197.5	90.2	0
26/06/2014	2.71	20.4	6.9	178	90.9	0.2
27/06/2014	3.31	22.9	11	208.3	91.9	0
28/06/2014	2.09	20.5	10.1	141.5	92.4	6.6
29/06/2014	2.33	20	9.8	166.7	92.8	3.2
30/06/2014	1.77	20	8.8	114	93.3	0
01/07/2014	3.34	21.9	7.8	207.7	93.7	0
02/07/2014	3.46	24.6	6.8	216.2	93.8	0
03/07/2014	4.27	25.5	10.1	244.7	94.1	0
04/07/2014	3.94	27.6	11.5	219.9	94.5	0

05/07/2014	2.14	22.2	14.6	134.4	94.7	2.6
06/07/2014	2.23	21.3	11.7	141.6	94.5	1.2
07/07/2014	3.21	23	8.7	201.3	94.8	0
08/07/2014	1.5	20.8	9.3	92.8	95.2	0.4
09/07/2014	3.21	22.3	12.7	193.2	95.6	0.2
10/07/2014	0.42	16.5	13.1	29.7	95.5	9.2
11/07/2014	0.34	16.4	12.5	28.1	95.9	2
12/07/2014	2.45	25.5	14.5	152.2	96.2	0
13/07/2014	2.83	25.8	14	176.9	96.7	0.2
14/07/2014	3.72	24.2	10.4	231.3	97	0
15/07/2014	3.58	26.8	14.5	214.3	97.2	0
16/07/2014	3.87	27.7	11.4	229.9	97.3	0
17/07/2014	3.3	28.2	15.1	191.2	97.3	0
18/07/2014	4.33	32	16.5	239.3	97.3	13.6
19/07/2014	2.53	27.9	17.1	147	97.4	4.6
20/07/2014	1.58	24.8	17.2	98.4	97.3	2.4
21/07/2014	2.6	26.1	16.1	159.4	97.4	0
22/07/2014	3.47	26.1	14.1	214	97.3	0
23/07/2014	3.5	27.2	14.9	213.3	97.5	0
24/07/2014	3.8	26.8	16.1	221.8	97.6	0
25/07/2014	2.99	26.9	16.9	177.5	97.6	0
26/07/2014	3.21	28.9	17.2	187.4	97.6	0
27/07/2014	1.91	24	15.5	113.8	97.7	0
28/07/2014	2.23	22.4	14.6	141.2	97.9	7.6
29/07/2014	3.19	26.1	14.8	200.3	98	6.2
30/07/2014	3.4	25.6	14.3	211.2	97.9	0
31/07/2014	3.31	25.4	12.9	201.2	97.9	0
01/08/2014	3.02	24.2	12.5	188.1	98	0
02/08/2014	2.61	24.3	14.4	162.7	98	4.6
03/08/2014	3.21	23.2	10.3	195.6	97.8	0
04/08/2014	2.37	23.2	10.3	143.5	97.8	0
05/08/2014	2.46	24.3	10.8	143.5	97.4	0
06/08/2014	2.7	25.2	15.5	167.9	96.8	9.2
07/08/2014	2.87	26.7	13.9	171.1	95.7	0
08/08/2014	1.03	22.4	13.5	70.3	93.5	28.8
09/08/2014	2.75	22.9	12.9	177.9	88.9	1.6
10/08/2014	1.76	21.3	13.9	113.8	83.6	19.2
11/08/2014	1.91	20.5	11.2	125.8	78.4	0.6
12/08/2014	2.44	20.7	10.4	154.1	74.4	0.2
13/08/2014	2.5	22.1	9.9	157.7	72.7	0
14/08/2014	1.58	21.9	12	112.9	70.9	2.6
15/08/2014	1.25	20	11.8	88	70.1	2.2
16/08/2014	2.13	20.2	10	132.3	69.7	0
17/08/2014	1.9	19.7	12.2	119.8	70.6	0.6
18/08/2014	1.98	19.8	9.8	133.1	69.2	0.2
19/08/2014	2.22	17.9	7.5	152.2	61.9	0
20/08/2014	2.08	18.6	6.4	140.2	59.7	0
21/08/2014	2.15	18.9	5.3	143.6	61.4	0
22/08/2014	2.2	20.1	10.4	148	62.4	0.6
23/08/2014	2.4	19.2	8.4	163.2	63.4	0.2

24/08/2014	2.07	19.2	5.7	142	62.5	0
25/08/2014	0.35	16.5	10.4	29.5	62.3	22
26/08/2014	0.34	15.9	12.5	30	61.2	16.4
27/08/2014	1.9	20.7	10.3	126.6	64.8	0
28/08/2014	1.95	22	13	128.6	64	0.6
29/08/2014	1.59	19.7	11.4	106.9	63.9	1
30/08/2014	1.71	19.1	12.9	111.1	64.4	0.6
31/08/2014	1.59	21.4	10	104.3	66.2	0
01/09/2014	1.1	19.8	8.4	75.6	67.2	0.2
02/09/2014	1.27	20.5	11.9	85.8	68.4	0
03/09/2014	1.79	21.9	11.5	119.2	68.9	0
04/09/2014	1.46	21.4	11.6	95.3	68.7	0
05/09/2014	0.99	20.2	12.9	65	69.5	0
06/09/2014	1.03	21.2	11.4	65.7	69.5	0
07/09/2014	1.68	21.4	9.7	116.9	70.8	0
08/09/2014	2.44	21.6	8.3	167.5	72.6	0
09/09/2014	2.04	21.1	8.1	143.7	73.4	0
10/09/2014	1.6	19.3	6.6	112.3	71.8	0
11/09/2014	1	18.1	8.5	62.4	72	0
12/09/2014	1.96	20.7	12.2	137.2	72.8	0
13/09/2014	1.73	21.1	12.6	118.2	73.4	0
14/09/2014	1.64	20.8	12.9	111.1	75.1	0
15/09/2014	1.42	21.7	11.6	96.6	76.3	0
16/09/2014	1.75	23	11.9	115.6	76.5	0
17/09/2014	1.04	20.5	15.4	68.4	76.8	0
18/09/2014	1.54	24.7	15.1	100.2	78	0
19/09/2014	1.86	26	15	122	78.5	5.8
20/09/2014	0.34	19.2	14.8	25.3	80.8	0
21/09/2014	1.46	18.1	8.7	107.8	82.4	0
22/09/2014	1.47	18.5	6.1	111.4	83.8	0
23/09/2014	1.42	19.2	4.8	102.7	85.9	0
24/09/2014	1.28	18.3	8.5	93	87.3	1.2
25/09/2014	1.26	19.4	5.4	89.9	88.5	0
26/09/2014	0.78	20.1	10.7	52.6	89.3	0
27/09/2014	0.91	21.2	8.1	62.4	90	0
28/09/2014	1.33	24.5	9.7	88.3	89.9	0
29/09/2014	0.42	19	10.7	31.8	90.1	0.4
30/09/2014	1.13	21.7	11.3	76.6	90.6	0
01/10/2014	1.11	21	10.6	76.9	91	0
02/10/2014	0.92	20.8	12.2	62.6	91.1	0
03/10/2014	1.44	22	11.7	97.7	91.3	0
04/10/2014	0.42	19.8	4.9	33.2	91.6	10
05/10/2014	1.21	17.1	1.9	100.1	91.7	0
06/10/2014	0.35	13.2	4	22.5	91.8	0.8
07/10/2014	1.14	15.2	4	87.8	92.1	10.2
08/10/2014	0.7	17.2	3.5	49	92.4	14.2
09/10/2014	1.19	17.6	8.4	81.1	92.7	1.2
10/10/2014	0.88	18	6.3	67.5	92.9	10.4
11/10/2014	0.65	17	6.4	52.3	93.1	5.2
12/10/2014	0.56	15.2	3.7	47.7	93.4	11.8

13/10/2014	0.53	17.4	11.6	40.8	93.8	20.4
14/10/2014	0.22	13.7	11.4	19.5	94.2	4
15/10/2014	0.46	15.1	11.6	36	94.4	3
16/10/2014	0.92	18	11.1	70.3	94.9	3
17/10/2014	0.78	19.5	11.9	57.2	95.1	0.4
18/10/2014	0.61	20.7	15.7	37.1	95.3	0
19/10/2014	1.08	19.9	13.2	72.9	95.4	0.6
20/10/2014	0.89	17.1	11.4	61.3	95.6	0
21/10/2014	0.96	14.4	7.9	52.4	95.8	1.4
22/10/2014	0.64	12.8	7	45.8	95.9	0
23/10/2014	0.52	16.2	9.7	36.2	96.1	0.2
24/10/2014	0.39	17.4	11.8	30.5	96.2	1.4
25/10/2014	0.66	15.1	7	50.1	96.6	0
26/10/2014	0.44	15.1	9	25.7	96.8	0
27/10/2014	0.95	18.7	9.8	72.9	97.1	0
28/10/2014	0.82	16.5	8.8	71.4	97.3	0
29/10/2014	0.06	14.7	12.3	7.8	97.5	2.6
30/10/2014	0.72	20.1	11.3	54.6	97.5	0.2
31/10/2014	0.89	21.9	10.9	68	97.6	0

Appendix 2. Environmental metrics recorded by the Agrii weather station in the Concept Pear Orchard at EMR during the 2015 cropping season.

N.B. The sweet cherry experiments were carried out in polytunnels and so the environmental metrics given here are not directly relevant to the cropping environment.

Date	ET_o (mm)	Air temperature (°C)		Average light intensity (W/m²)	RH (%)	Rainfall (mm)
		Maximum	Minimum			
01/04/15	2.16	11.4	4.8	149.3	62.4	0.2
02/04/15	1.75	11.9	5.7	150	64.7	2
03/04/15	0.53	11.8	6.1	49.1	66.1	1
04/04/15	0.69	8.9	4.9	61.3	66.6	0.4
05/04/15	1.62	11.5	1.4	141.9	66.6	0
06/04/15	1.54	14.5	-0.5	135.4	66.1	0
07/04/15	2.32	17.1	1	190.4	64.6	0
08/04/15	1.77	16.7	5.1	130.3	64.8	0
09/04/15	1.96	16.6	4.5	160	66.1	0
10/04/15	2.33	20.5	2	146.3	65.6	0
11/04/15	2.17	13.8	4.4	157	65.3	1.4
12/04/15	2.81	16.3	1	216.4	64.1	0
13/04/15	1.78	16.3	6.5	131.4	63.9	0
14/04/15	3.47	22.7	4.2	233.3	63.7	0
15/04/15	3.67	25.5	5.6	226.9	64.6	0
16/04/15	1.78	15.5	7.7	136	65.3	0
17/04/15	2.25	12.9	6.5	189	66.4	0
18/04/15	2.54	13.2	5.3	219	65.7	0
19/04/15	1.64	12.3	3.6	137.2	64.7	0
20/04/15	3.09	17.4	3.2	237.6	64	0
21/04/15	3.14	16.4	4.2	243.8	63.4	0
22/04/15	1.83	13.2	5	160.7	63.5	0
23/04/15	2.51	16	3.9	196.9	63.3	0
24/04/15	2.4	19.8	2.8	174.3	63.5	0
25/04/15	1.87	18.4	10.2	129.6	64.9	0.8
26/04/15	0.44	11.1	2.9	41.4	64.9	3.2
27/04/15	2.13	14.4	1.7	179	65	0
28/04/15	2.63	13.8	3.1	197.6	64.6	0
29/04/15	1.17	12.6	4.8	100.1	64	6.6
30/04/15	2.51	16.1	2.8	195.5	64.2	0
01/05/15	1.78	12.1	6	141.3	63.5	0
02/05/15	1.26	14.7	6.2	85.4	62	0.8
03/05/15	1.51	18.3	10.6	110.3	61.2	3.6
04/05/15	1.92	18.9	10.5	136.5	59.4	9.6
05/05/15	2.26	15.8	10.6	151.3	58.8	3
06/05/15	1.75	14.6	8	134.9	58.9	2
07/05/15	2.38	17.6	7.5	170.8	58.7	0
08/05/15	1.68	17.8	7.1	113.6	58.4	1.2
09/05/15	2.41	18.4	7.1	163.6	57.5	0.2
10/05/15	2.91	19.5	6.4	208.7	55.5	0
11/05/15	2.86	22.5	8.9	186.1	53.6	0
12/05/15	2.69	18.5	5.8	181.4	53.5	0

13/05/15	3.19	21.3	3.3	220.3	53.2	0
14/05/15	0.27	10.2	5	26.8	52.2	16
15/05/15	1.59	15.5	7.1	119.7	52.9	0.8
16/05/15	2.98	19.8	7.5	201.3	52.7	0
17/05/15	2.71	18.7	4.3	188	51.8	0
18/05/15	1.5	16.3	7.3	103.7	52.2	2.2
19/05/15	2.05	15.8	5.5	164.3	51.7	2.4
20/05/15	2.1	16.4	4.5	158.7	51.7	0
21/05/15	2.56	19.8	2.7	166.7	51	0
22/05/15	2.19	22.1	6.2	149.4	48.8	0
23/05/15	1.05	17.5	9.5	73.7	47.2	0
24/05/15	1.62	20.9	7.4	107.2	47.5	0
25/05/15	1.42	16.5	8.8	98.6	48.3	0
26/05/15	2.51	20.3	8	169.8	50	0
27/05/15	3.14	21.4	5.4	213.3	49.2	0
28/05/15	2.62	18.1	9.3	165	49.7	0
29/05/15	1.09	14	5.6	85.5	49	6.6
30/05/15	2.59	17.8	4.3	175.5	50.2	0
31/05/15	0.73	15.3	7.1	51.6	50.7	2.8
01/06/15	1.84	16	6.3	127	49.5	0
02/06/15	0.86	16.9	11.1	60.5	49.8	1.6
03/06/15	2.74	20.8	8.5	176.1	51.4	0
04/06/15	3.66	22.8	5.8	235.7	52.6	0
05/06/15	3.27	26	10.4	188.6	54.9	11.2
06/06/15	2.99	20.3	7.2	191.7	56.7	0
07/06/15	2.78	20.8	5.5	181.4	58.6	0
08/06/15	2.81	19.1	5.8	187	59.1	0
09/06/15	2.02	16.1	7.1	130.1	59.3	0
10/06/15	2.02	16.6	9.1	143.9	58.8	0
11/06/15	3.63	22.3	11.4	232.1	59.3	0
12/06/15	1.93	24.5	11.9	118.8	60.4	8.2
13/06/15	1.47	20.8	11.3	93.4	62.5	0
14/06/15	0.68	18.3	9.9	50	64.7	0
15/06/15	2.82	18.6	6.3	199.8	65.4	0.8
16/06/15	2.77	23	5.2	176.6	66.4	0
17/06/15	2.92	24.8	9.5	174.5	66.9	0.2
18/06/15	3.13	22.4	13	204.6	67.5	0.2
19/06/15	2.34	20.7	11.5	149.6	68.4	0
20/06/15	1.17	19.1	10	78.7	69.1	3.4
21/06/15	2.4	20.2	12.6	139.7	69.8	0
22/06/15	1.34	18	10.1	92.9	69.8	5.2
23/06/15	1.77	19.5	9.8	114.9	70.9	0
24/06/15	3.18	23.5	8.5	194.1	73.4	0
25/06/15	3.16	26.9	9.4	175.1	76.9	0
26/06/15	3.43	26	9.7	207	80.3	0
27/06/15	3.66	25.2	11.4	222.3	83.4	0
28/06/15	2.12	22.2	13.6	127	89	0
29/06/15	3.84	25.9	11.6	231.1	92.6	0
30/06/15	4.72	28.7	9.4	265	94.4	0
01/07/15	3.68	34	17.9	174.6	95.6	0

02/07/15	1.92	25.1	15.2	117.5	96.3	0.2
03/07/15	3.92	26.1	12	242.3	96.7	5
04/07/15	4	26.6	13.3	242	96.5	0.2
05/07/15	1.73	22	12.3	111.4	96	6
06/07/15	3.54	23.3	10.8	225	95.7	0
07/07/15	2.56	22.8	11.4	160.3	95.2	0.2
08/07/15	1.96	21.7	12.8	116.2	94.7	0
09/07/15	3.73	23.3	9.2	242.3	93.9	0
10/07/15	4.29	25	9.2	261.5	93.3	0
11/07/15	3.99	26.5	12.3	230.4	92.3	0
12/07/15	1.21	19.8	14.2	77.9	92.1	0
13/07/15	0.98	20.3	16	64.1	91.8	0.4
14/07/15	1.22	21.5	16	76.8	91.3	0.6
15/07/15	2.2	24.8	14.8	139.5	90.2	0.2
16/07/15	2.11	24.3	14	125.3	89	0
17/07/15	2.69	23.1	13.4	156.8	87.5	0
18/07/15	3.47	24.2	11.5	219.3	86.4	0
19/07/15	3.31	23.9	13.3	206.2	86.8	0.6
20/07/15	1.32	22.2	12.4	83.7	90.3	0.2
21/07/15	3.71	24.5	12.4	229.8	93.6	0
22/07/15	2.18	23	11.6	131.9	94.6	0
23/07/15	2.81	22.5	9.2	176	95.6	0
24/07/15	0.44	17	12.4	36.3	96.4	23.4
25/07/15	2.57	20.6	10.4	180.4	96.9	1.8
26/07/15	0.52	16.2	10.2	47.3	97.3	7.8
27/07/15	2	20.7	14.4	118.7	97.4	0.2
28/07/15	2.34	19.6	11.1	136.2	96.7	0
29/07/15	2.18	19.7	9	138.7	96.3	1
30/07/15	2.02	20.2	8.7	138.7	96.3	0.2
31/07/15	2.13	22	5.8	135.8	95.3	0
01/08/15	3.14	22.9	6.3	197.2	94.5	0
02/08/15	3.37	25.2	9.3	209.2	93.1	0
03/08/15	2.22	24.9	12.4	137.3	92.3	0
04/08/15	2.46	21.6	12.7	150.1	91	0
05/08/15	2	22.9	12.6	119.1	89.9	0
06/08/15	1.87	23	11	114	87.5	0
07/08/15	2.88	27	8.5	178.7	86.3	0
08/08/15	2.13	26.3	11.3	127.2	82.5	0
09/08/15	3.75	27.9	8.9	211.8	81.4	0
10/08/15	2.32	26	15.5	141	81.8	0
11/08/15	1.39	22.1	14	88.9	77.3	1.2
12/08/15	1.5	21.1	15.2	93.3	73.1	1
13/08/15	0.51	20.5	17.3	38.1	71.9	16.4
14/08/15	1.63	23	15.2	101.6	71.4	2.4
15/08/15	2.43	22.1	10.4	163.8	70.7	0
16/08/15	0.96	20	8.5	65.8	70.5	0
17/08/15	2.1	22.7	8.9	142.4	70.7	0
18/08/15	0.86	17.9	12.9	50.6	68.1	0
19/08/15	2.09	22.3	11.6	133.9	63.1	2.6
20/08/15	1.19	20.6	14.4	80.2	62	2.2

21/08/15	2.57	26.6	15.3	151.7	61.7	0
22/08/15	3.16	29.4	13	176.4	60.3	0
23/08/15	1.33	21.4	11.3	79.3	59.2	2.2
24/08/15	0.64	17.7	11.2	49.2	58.5	21.6
25/08/15	0.83	17.7	10.8	64.2	57.9	6.2
26/08/15	0.61	19.4	13.5	45.1	56	5.2
27/08/15	1.17	18.3	10.8	77.8	51.7	0.2
28/08/15	1.93	20.7	8.9	129.7	49.9	0
29/08/15	1.48	22.7	12	97.5	49.3	3.6
30/08/15	0.99	20.6	15.1	65.8	48.8	2.2
31/08/15	0.22	15.7	13.4	19.9	45.8	9
01/09/15	1.11	17.9	9.8	81.3	47.3	3.4
02/09/15	1.42	19.3	7.2	104.1	44.9	0
03/09/15	1.03	16.3	8.5	77.6	44.1	0.2
04/09/15	0.79	16.5	8	60.1	44.7	0
05/09/15	0.68	15.9	6	49.5	44.6	0
06/09/15	1.81	18.4	4.8	136.9	43.5	0
07/09/15	1.18	17.9	6.8	87.6	43	0
08/09/15	0.91	16	7.5	67.9	46.4	0
09/09/15	1.47	20	12.4	95.2	48.8	0
10/09/15	2.31	21.8	8.4	156.8	48.2	0
11/09/15	2.15	22.6	7	142.3	47.6	0
12/09/15	1.83	20.6	9.4	123.3	48.3	1.2
13/09/15	0.8	15.7	7.4	59.4	48.5	0
14/09/15	1.19	17.7	9.5	89.9	47.4	9.4
15/09/15	0.96	18.3	8.6	68.2	47.3	3
16/09/15	0.14	15	9.6	15.4	47.3	23
17/09/15	1.29	17.4	9.9	97.4	50.1	1
18/09/15	1.05	19	9.8	82.3	59.6	5.8
19/09/15	1.52	19.2	7	116.3	72.3	0.2
20/09/15	1.63	20.2	5.7	117.3	75.8	0
21/09/15	0.51	16.2	9.1	43.7	77.2	6.4
22/09/15	0.52	12.6	7.2	46.2	78.9	13.8
23/09/15	1.58	17.7	7.5	119.5	80.4	0
24/09/15	1.04	18.4	8.8	70.2	81.4	1
25/09/15	1.21	17.6	4.8	94.2	81.7	0
26/09/15	1.28	17.5	3.6	93.5	81.4	0
27/09/15	1.49	18.2	7.1	109.8	82.2	0
28/09/15	1.5	18.7	5.6	109.8	82.8	0
29/09/15	1.6	18.2	6.8	116.7	83.4	0
30/09/15	1.57	18	8.6	113.7	83.7	0
01/10/15	1.33	17.7	6.9	95.2	83.7	0
02/10/15	1.49	19.2	4.9	111.8	83	0
03/10/15	0.78	16.8	5.2	60.9	82.6	0
04/10/15	1.2	18.1	4	96.5	83.2	0
05/10/15	0.23	17.1	13	19.2	84.1	6.4
06/10/15	0.59	18.3	13.7	41.4	86.5	6
07/10/15	0.32	15	9.4	26.1	88.3	0.4
08/10/15	1.01	17.4	4.8	83	89.5	0
09/10/15	1.07	17.7	2.6	84.6	90.2	0

10/10/15	0.65	15.8	6.6	52.6	90.9	0
11/10/15	1.05	15.3	7	86.1	91.3	0
12/10/15	0.55	13.5	6.1	41.5	91.4	0
13/10/15	0.49	12.1	5.6	33.5	91.3	0
14/10/15	0.67	13.9	5.6	50	91.2	0.2
15/10/15	0.25	12.5	7.7	22.3	91	1.2
16/10/15	0.11	11.1	10.3	12.2	90.9	3.4
17/10/15	0.35	12.6	9.9	27.2	90.3	0
18/10/15	0.68	15.8	9.8	54.3	90.1	0
19/10/15	0.3	13.9	8.3	25.8	88.2	0
20/10/15	0.83	15	4.4	71.5	85.9	0
21/10/15	0.23	13.6	4.5	23.5	83.8	6.4
22/10/15	0.37	14.5	9.1	26.8	80.8	0
23/10/15	0.37	13.8	8.7	28.8	80.8	0
24/10/15	0.25	14.5	7.2	17.7	82.8	4.4
25/10/15	0.66	13.4	2.3	62.1	86	4.4
26/10/15	0.7	15.3	2.3	63.1	87.4	0
27/10/15	0.69	18.3	10.2	54.6	88.1	0
28/10/15	0.55	15.9	7.1	47.6	90.1	18.8
29/10/15	0.28	14.4	8.2	24.8	90.6	0
30/10/15	0.45	16.3	11.6	34.4	90.5	2.6
31/10/15	0.61	15.5	4.9	54.2	90.4	0