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
Report:	Annual report, April 2015
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Key staff:	Mike Davies, Dr Eleftheria Stavridou, Clare Hopson, Helen Longbottom,
Location of project:	East Malling Research
Industry Representatives:	Mark Holden (Adrian Scripps), Nigel Kitney (Old Grove Farm) and Will Dixon (AR Neaves & Sons)
Date project commenced:	01 April 2013
Date project completed:	31 March 2016

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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.

Michael J. Davies
Project Manager
East Malling Research

Signature ..... Date .....

Report authorised by:

Dr Mark A. Else
RECP Programme Leader
East Malling Research

Signature: Date: 30 April 2015

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GROWER SUMMARY

Headlines

- Results from the non-irrigated treatment 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/M.9’ and ‘Braeburn/M9’.

Background and expected deliverables

The droughts of 2011-2012, the move to more intensive growing systems and the on-going reform of the abstraction licencing system highlight the need for tree fruit growers to use water for irrigation more efficiently. The challenge is to put in place measures that improve irrigation water use efficiency, 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. Irrigation of high-intensity orchards is generally needed to optimise productivity, consistency of cropping and fruit quality, but improved guidelines for UK growers need to be developed as the impacts of climate change alter evaporative demand and summer water availability. 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 late 2015, drip irrigators will have to demonstrate an efficient use of irrigation water. A new water-saving irrigation test regime (ITR) has been developed for high-intensity pear production in TF 198. Water savings of over 50% were achieved, compared to current commercial practice, and yields and quality of marketable fruit were maintained. The approach is now being tested on a commercial farm in a project funded by Marks and Spencer plc and led by Worldwide Fruit Ltd.

The AHDB Horticulture Tree Fruit Panel has identified the need to develop targeted irrigation strategies to optimise water use efficiency, yields and fruit quality for other high-intensity tree fruit crops. In this project, scientifically-derived guidelines are being developed that optimise irrigation water use efficiency for ‘Gala/M.9’, ‘Braeburn’/M.9, ‘Merchant’/Gisela 5 and ‘Kordia’/Gisela 5. Soil matric potentials and midday stem water potentials that slow rates of fruit expansion and photosynthesis will be identified and this information will be used to develop and test ITRs for each cultivar. The effects of the ITRs on shoot physiology, fruit yields and quality will be determined and compared to unscheduled commercial and non-irrigated controls. The proposed research will provide new guidelines to optimise water (and fertiliser) use efficiency in high-intensity apple and sweet cherry orchards on a range of different soil types.

Expected project deliverables are:

- Irrigation guidelines to optimise water use efficiency in high-intensity apple and sweet cherry orchards on a range of soil types used for tree fruit growing
- Increased awareness of the effects of scheduled, unscheduled and no irrigation on canopy growth, fruit quality and consistency of cropping
- Reduced water usage by up to 40% (compliance with legislation, maintenance or expansion of current production, despite increasingly limited and expensive freshwater supplies)
- Improved sustainability (more efficient use of water, lower production costs)
- Reduced environmental impact (lower abstraction rates, reduced nutrient leaching)
- Improved fruit flavour (less dilution of essential flavour compounds)
- Greater resource use efficiency to enable sustainable intensification despite limited freshwater supplies
- Demonstrable compliance with legislation

Summary of the project and main conclusions

The aim of this project is to optimise water use efficiency (WUE) without reducing Class 1 yields or quality in apple and sweet cherry. To optimise WUE, the frequency and duration of irrigation events must be managed carefully to avoid run-through of water and nutrients past the rooting zone. In order 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 probes, which measure soil matric potential, and Decagon 10HS probes, which measure soil volumetric moisture content, are being used to provide this information.

Scientific approach

The approach used in this project was to impose temporary and gradual soil drying so that the soil matric potential (water availability) within the rooting zone at which tree physiology is first affected, could be identified at different stages of crop development. Midday stem water potential is very sensitive to changes in soil water availability and is often the first indication that plants are experiencing a degree of water stress. Identifying the values of midday stem water potential at which agronomically important traits such as rates of fruit expansion and photosynthesis are first slowed, will help to inform the development of the Irrigation Test Regimes (ITR) for each variety. Since the aim of this work is to develop a ‘low-risk’ strategy

for commercial growers, the lower irrigation set point was set 100 kPa above the value at which shoot physiological responses are first detected. Soil matric potentials are negative values and they become more negative as the soil dries and water availability decreases. For example, soil at field capacity would have a matric potential of *ca*. -10 kPa whereas the matric potential of soil at permanent wilting point would be *ca.* -1,500 kPa.

Apple

The experiments were conducted in a high intensity mixed 'Gala/M.9' and 'Braeburn/M9' orchard at EMR. The trees were planted in spring 2009 at an in-row spacing of 1 m, with 3.5 m between rows. All trees within the orchard received the same crop husbandry practices (*e.g*. pest and disease spray programmes, fertiliser application, weed control). Separate irrigation lines were installed along the centre of each row at a height above the ground of 50 cm to deliver water to each treatment via 1.6 L h^{-1} pressure compensated drippers positioned 50 cm apart.

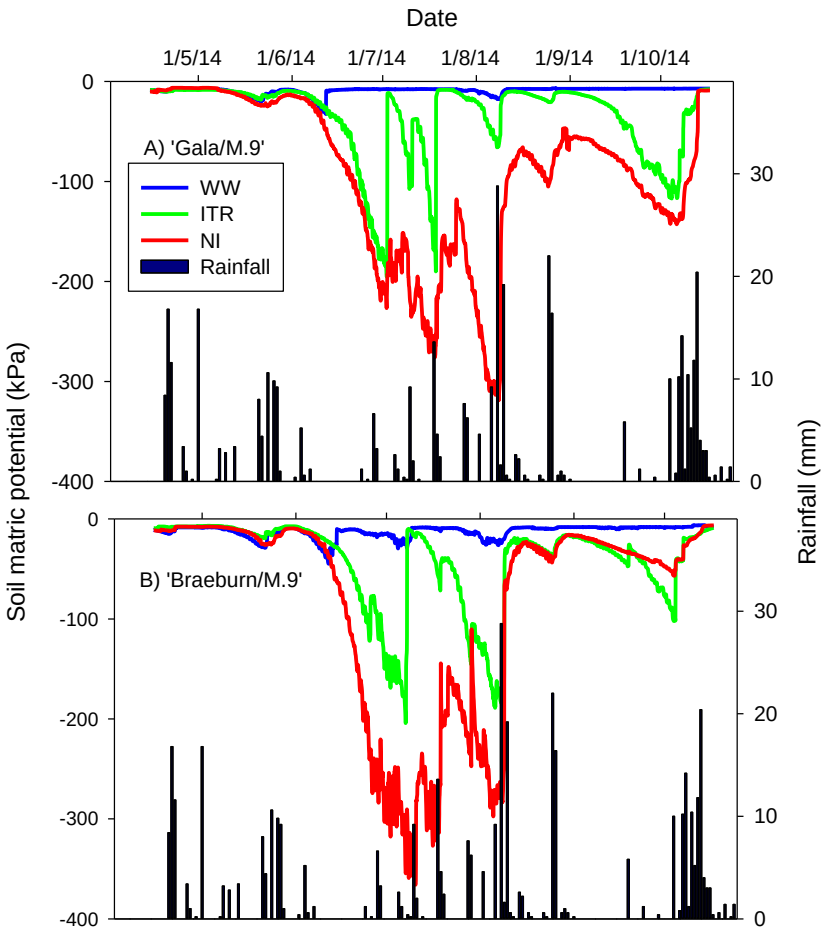

Figure 1. A) Changes in soil matric potential averaged over the top 60 cm of soil in each of the three irrigation treatments applied to 'Gala/M.9' trees in 2014. Rainfall throughout the experiment is also shown. B) Changes in soil matric potential at 20, 40 and 60 cm depth in 'Braeburn/M.9' trees under the three irrigation treatments.

Three irrigation treatments were imposed on both 'Gala/M.9' and 'Braeburn/M9'' (Figure 1); 1) Commercial control (CC) where irrigation decisions were taken by EML's Farm Manager Mr Graham Caspell; 2) An Irrigation Test Regime (ITR) in which irrigation was applied when soil matric potential averaged over 20, 40 and 60 cm and reached the irrigation set point of -200 KPa; 3) No Irrigation (NI) to determine the effects of increasing soil moisture deficits on tree physiological responses and fruit size.

'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, Class 1 yield and number were not affected.

'Braeburn/M9' 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 Class 1 fruit were similar to those in the CC treatment. Significant reductions in midday stem water potential were detected in the NI treatment in which the average soil matric potential fell to -350 kPa before sporadic rainfall raised values to -110 kPa, then to field capacity. Even though the NI trees experienced mild drought stress, the number and yield of Class 1 fruit were not affected.

These data suggest that frequent irrigation to maintain the soil near to field capacity is not necessary to deliver good commercial yields in 'Gala/M.9' and 'Braeburn/M9' and adopting this approach will increase leaching of N and other nutrients past the rooting zone (see Annual Report for TF 214). Adopting an irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) could be used to optimise both on-farm water use efficiency and crop productivity. The effects of the applied soil water deficits on return bloom will be assessed in 2015.

Sweet cherry

The experiments were conducted on 'Merchant/Gisela 5' and 'Kordia/Gisela 5' in a mixed cultivar sweet cherry orchard at EMR (Figure 2). The trees were planted on 22 April 2011 at an in-row spacing of 3 m between trees, with 3 m between each variety 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 N^{o}6 tree stake.

Figure 2. Two rows of the 'Merchant/Gisela 5' trees in the mixed sweet cherry orchard at EMR. Photo taken on 15 May 2014.

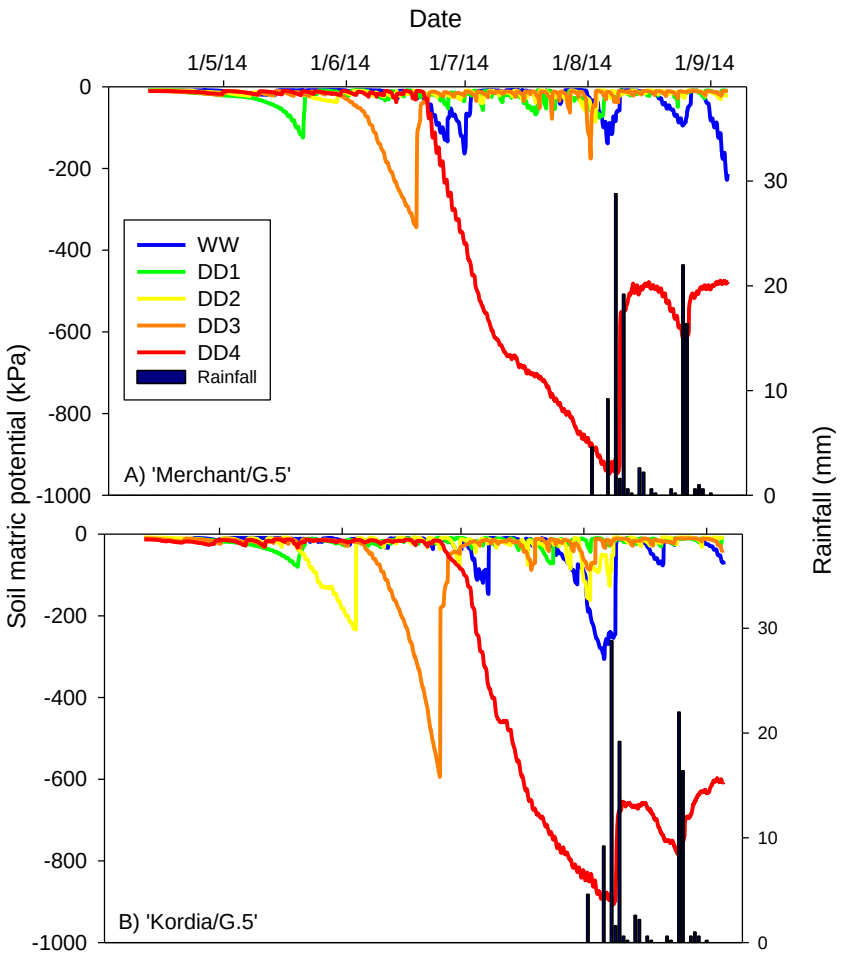

Figure 3. A) Changes in soil matric potential averaged over the top 60 cm of soil in each of the five irrigation treatments applied to 'Merchant/Gisela 5' trees in 2014. Covers were removed on 4 August 2014 and rainfall thereafter is also shown. B) Changes in soil matric potential at 20, 40 and 60 cm depth in 'Kordia/Gisela 5' trees under the three irrigation treatments.

Two experiments were set up in the orchard using the West row of each double row, with five irrigation treatments per experiment. Irrigation in the CC treatment was applied to maintain the average soil matric potential above -40 kPa throughout the season and Deficit Irrigation (DI) treatments of different duration and intensity were imposed during fruit growth Stages I, II and III, and postharvest (Figure 3). DI treatments were imposed to determine whether fruit growth stages were differentially sensitive to soil moisture deficits, otherwise average soil matric potential was maintained above -40 kPa. Irrigation was also withheld post-harvest to some trees to test the effects of soil moisture deficits during the flower initiation phase on cropping potential in the following year.

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. This variability meant that it was not possible to identify if specific fruit growth stages were sensitive to mild soil drying since there were no statistically significant treatment effects on fruit number or yield, and the work will be repeated in 2015. In the post-harvest treatment, midday stem water potentials were significantly lowered once the average soil matric potentials fell beyond -350 kPa and the effects of this treatment on return bloom, Class 1 yields and fruit quality will be determined in 2015.

In 'Merchant/Gisela 5', average soil matric potentials fell to -115, -22, -332 and -925 kPa during the four deficit irrigation treatments. Similar physiological responses to those described for 'Kordia' were seen in 'Merchant', but 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 2015, soil matric potential will be maintained above -60 kPa during Stages I and II, and above -200 kPa during Stage III, and the effects on Class 1 yields will be compared with those from CC trees. The effects of soil moisture deficits during the flower initiation phase (the post-harvest treatment) in 2014 on yields and quality of Class 1 fruit in 2015 will also be determined.

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 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 and the effects of this treatment on return bloom, Class 1 yields and fruit quality will be determined in 'Kordia' in 2015.
- 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 2015, soil matric potential will be maintained above -60 kPa during Stages I and II, and above -200 kPa during Stage III in each of the two cultivars, and the effects on Class 1 yields will be compared with those from CC trees.
- 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 2015 will be determined.

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). A partial cost/benefit analysis will be carried out in Year 3 in which the three irrigation treatments imposed at EMR will be compared. Differences in Class 1 yields obtained under the three regimes will be used to estimate the gain or loss of revenue which could be balanced against the expenditure needed to implement the different irrigation strategies. The potential to target fertilisers more efficiently to the rooting zone under the ITRs may be of more immediate interest to some growers

since there is the potential to reduce both inputs and direct costs; this work will be carried out by Dr Eleftheria Stavridou in AHDB Horticulture project TF 214 at EMR.

Action points for growers

- Consider installing probes 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 accurately record 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’, adopting an irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) will optimise both on-farm water (and fertiliser) use efficiency and crop productivity.
- Maintain soil near to field capacity during fruit growth Stage 1 to avoid the negative effects of limited soil water availability on marketable yields of ‘Merchant’.

SCIENCE SECTION

Introduction

Irrigation is essential for the successful establishment and continued productivity of high-intensity tree fruit growing systems. Modern and traditional orchards increasingly rely on irrigation to deliver the consistency of yields and quality needed for a profitable business[1]. However, 90% of tree fruit growers farm in areas where water resources have already been classified by the Environment Agency (EA) as under increasing stress[2] and abstraction rates in these areas are currently unsustainable[3]. 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. Increases in agricultural water demand in the 2050s in England and Wales range from 25% to 189% of current demand[4] (EA, 2008). One useful indicator of aridity that is widely used is the potential soil moisture deficit (PSMD) which represents the balance between rainfall and potential crop water use over the year. It is estimated that in the south-east, the average annual maximum PSMDs that currently occur every five years will occur every two years by 2080 and deficits that currently occur every fifteen years will occur every five years by 2080[5]. Therefore, there will be an increasing reliance on irrigation to ensure profitable tree fruit production. 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), tree fruit growers have highlighted their concerns 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, Defra and the Welsh Government have been working with the Environment Agency and Ofwat on the abstraction licensing system and Defra's consultation on abstraction reform closed on 28 March 2014. The resulting changes in the abstraction licencing system will be rolled out gradually from late 2015 and all drip irrigators will require an abstraction licence. They must also be able to demonstrate a need for, and an efficient use of, irrigation water before the time-limited abstraction licences are renewed.

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[6]. In AHDB Horticulture-funded research in the Concept Pear Orchard at EMR (TF 198), we developed an irrigation scheduling 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[7]. There is a 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 regimes to control vegetative growth, improve fruit quality and storage potential and optimise the use of valuable resources.

In this project, irrigation test regimes (ITRs) are being developed for two apple and two sweet cherry varieties to try to optimise water use efficiency (WUE) without reducing Class 1 yields or quality. The approach is 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, are triggered. The range of soil ψ_m within the rooting zone at which these responses begin to diverge significantly from well-watered values can then be identified. This process is 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). The lower irrigation set point at each developmental stage will be set at 100 kPa above the value that tree physiology becomes affected (ψ_m values are negative). Irrigation will only be applied once the lower set-point has been reached and the duration of irrigation will be 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 and so this should perhaps be avoided. Soil water deficits post-harvest applied to suppress vegetative growth can also reduce fruit firmness and soluble solids content (SSC) after cold storage in the following year, presumably through effects on assimilate partitioning during the time of flower bud initiation. Clearly, it will be 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 sweet cherry cv. 'New Star' and these values will help to inform our strategies for developing efficient irrigation regimes for sweet cherry/rootstock combinations 'Merchant/Gisela 5' and 'Kordia/Gisela 5'. Similar threshold values of ψ_{ms} have been derived for several apple cultivars and these will be compared against those found to limit fruit size and number in dessert apple/rootstock combinations 'Gala/M9' and 'Braeburn/M9. Identifying the soil matric and midday stem water potential 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.

The information obtained in Year 1 was used to devise and test an ITR for each apple cultivar in 2014. Irrigation treatments were imposed from six weeks after full bloom until harvest. Irrigation was applied only when the average soil ψ_m reached the irrigation set point for each variety, and so the frequency of irrigation events was determined by the rate of soil drying/crop water use. The duration of irrigation events was adjusted to ensure that losses of irrigation water past the rooting zone were minimised. Effects of the ITR treatment on fruit expansion, marketable yields and quality were compared to those of the NI treatment where, in the absence of significant rainfall, we anticipated that average soil ψ_m would fall below the values recorded in 2013. The NI treatment should also enable us to identify the ψ_{ms} values at which photosynthesis and FER were first affected in each variety. Similar work also commenced with two sweet cherry varieties 'Kordia/Gisela 5'' and Merchant/Gisela 5' in a covered orchard at EMR in 2014.

Materials and methods

Apple

The experiments were conducted in a high intensity mixed 'Gala/M9' and 'Braeburn/M9' orchard at EMR. The trees were planted in spring 2009 at an in-row spacing of 1 m, with 3.5 m between rows. Each tree was supported by a 2.4 m spindle stake and each individual row contained a single variety. 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 cultivar. Irrigation water was supplied by irrigation lines positioned along the centre of each row at a height above the ground of 50 cm, with 1.6 L h^{-1} pressure compensated drippers positioned 50 cm apart, directly next to each tree and mid-way between adjacent trees within the row.

Experimental design

Two experiments were set up in the orchard, one for each cultivar, with three irrigation treatments per experiment. The three irrigation treatments were:

1. A commercial control (CC), in which the frequency and duration of irrigation events was decided by Mr Graham Caspell, EMR's farm manager.
2. Irrigation Test Regime (ITR), in which irrigation was withheld, so that gradual soil drying and the associated decline in soil ψ_m triggered physiological responses to limited soil water availability.
3. No irrigation (NI) throughout the season i.e. these trees were rain-fed. This treatment was imposed to test whether irrigation was necessary to ensure high marketable yields, good fruit quality and consistency of cropping in high intensity apple production.

Within each experiment, three rows for each cultivar were selected and the trees within each row were divided into five-tree plots; measurements were made on the central three trees of each plot and those on either side acted as guard trees between the different irrigation treatments. Each experiment was conducted in a completely randomised block design with nine blocks, each of three plots (*i.e.* 9 x 3 = 27 plots and 27 x 3 = 81 trees in total). Each row contained three experimental blocks. All physiological measurements were conducted on the central tree in each plot, whilst three trees were used to record yields of marketable fruit. Within each block, a fourth plot was included to accommodate research conducted as part of AHDB Horticulture TF 214 which began in April 2014.

The ITR was imposed by installing a separate irrigation line for each cultivar and the frequency and duration of irrigation events to these plots was adjusted using Galcon irrigation controllers. Drip lines were removed from plots receiving the NI treatment.

Measurement of soil matric potential and volumetric soil moisture content

Soil matric potential in each of the three treatments was monitored hourly from 15 April until 17 October 2014 using MPS2 probes (Decagon Devices Ltd) connected to EM50G data loggers with telemetry for the CC and ITR treatments, and EM50 data loggers for the NI treatment. MPS2 probes were inserted at a depth of 20, 40 and 60 cm to ensure that changes in soil ψ_m throughout the entire rooting zone were measured. Probes were positioned directly below an emitter, within 20 cm of the trunk of the middle tree in the plot. In each experiment, MPS2 probes were placed in three plots for the CC, NI and ITR treatments. Data loggers were downloaded daily and the average soil ψ_m over 60 cm soil depth for each treatment was calculated. Volumetric soil moisture content was also monitored continuously, using Decagon 10HS soil sensors positioned at a depth of 50 cm and within 20 cm of the trunk of the same tree under which the MPS2 probes were positioned. 10HS probes were placed in three plots in the CC, NI and ITR treatments. To monitor the frequency, duration and volume of irrigation events, three ECRN rain gauges connected to EM50G data loggers were positioned directly below individual emitters within the CC and ITR treatments of both experiments.

Commercial irrigation regime

Irrigation scheduling in the CC treatment was decided by EMR's Farm manager. Irrigation was applied for one hour daily until the end of October, after which all trees were left un-irrigated throughout the autumn and winter 2014-2015.

Irrigation scheduling in the ITRs

Irrigation was withheld from the ITR and NI treatments from 1 May 2014 and only applied to the ITR trees once the average soil ψ_m within the rooting zone had reached -200 kPa. However, a heavy rainfall event at EMR on 8-9 August 2014 returned the soil throughout the rooting zone to field capacity. Thereafter, the extent of soil drying was relatively low due to further rainfall. Consequently, only two irrigation events were scheduled to the 'Gala/M9' trees in the ITR treatment and one to the 'Braeburn/M9' ITR trees during the growing season. Rainfall data was collected form a weather station supplied and maintained by Agrii located in the Concept Pear Orchard at EMR.

Physiological measurements

Tree physiological measurements were made when the average soil ψ_m within the rooting zone of NI trees reached specified set points or just before the average soil ψ_m reached -200 kPa in trees under the ITR treatment when an irrigation event would be scheduled. These measurements were carried out on the central tree in each experimental plot to detect if the soil moisture availability became limiting for agronomically important traits in each cultivar.

Stomatal conductance (g_s) and rates of photosynthesis of a mature fully-expanded leaf were measured using a portable photosynthesis system (Li-Cor). Midday stem water potential of a mature, fully-expanded leaf was measured by first enclosing leaves in aluminium foil sleeves for 1.5 h prior to measurement of stem water potential with a Scholander pressure chamber. Leaves were excised, removed from the sleeves and placed within 30 s into a Skye SKPM 1400 pressure chamber (Skye Instruments Ltd, UK) and the applied pneumatic pressure at which xylem sap first appeared at the cut surface of the petiole was recorded. Fruit expansion rate (FER) was estimated by calculating the spherical volume of two newly set fruit, one tree in each block, from twice weekly fruit length and width measurements made with digital callipers.

Fruit yield and quality

Fruit was harvested from 'Gala/M9' trees on 11 September 2014 and from 'Braeburn/M9' trees on 15 September 2014, following advice from EMR's commercial Farm Manager. Apples were picked from the three central trees and pooled within each plot. The total number and fresh weight of fruit from each three-tree plot was determined for Class 1, 2 and waste fruit. Yields were also separated into fruit with scab and those without scab and then into the relevant categories for cv. 'Gala' due to a high proportion of the fruit suffering from this disorder. Class 1 fruit were graded into different size categories according to fruit diameter (55-60, 60-65 and 65+ mm) and Class 2 fruit were graded in to <55 or where the colour criteria of 30% redness for cv. 'Braeburn' was not met. For fruit quality measurements, a twenty fruit sub-sample of Class 1 and 2 fruit was selected from the three size categories such that the size distribution reflected that of the pooled plot sample.

Fruit firmness (N), on two sides of each fruit in the twenty fruit sample, was measured using an LRX penetrometer (Lloyds Instruments Ltd) with an 11 mm penetration probe, providing values of force at maximum load. Samples of juice were also extracted and pooled from each fruit in a twenty fruit sample and soluble solids content (SSC [%BRIX]) was measured with a digital refractometer (Palett 100, Atago & Co. Ltd, Tokyo, Japan).

Blossom counts were assessed on 2 and 3 April 2014 to see whether the previous year's irrigation treatments had affected return bloom. The middle tree of each three-tree plot was used for blossom counts and auxiliary, spur and terminal buds were counted and then combined to give the total number of buds.

Statistical analysis

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

Sweet cherry

The experiments were conducted on 'Merchant/Gisela 5' and 'Kordia/Gisela 5' in a mixed cultivar sweet cherry orchard at EMR. The trees were planted on 22 April 2011 at an in-row spacing of 3 m between trees, with 3 m between each cultivar in staggered double rows and 4 m between each double row. Each double row contained a single cultivar and each tree was supported by a No. 6 tree stake. Trees 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 cultivar. Irrigation water was supplied by irrigation lines running along each row on the ground, with 1.6 L h-1 pressure compensated drippers positioned 60 cm apart, directly next to each trunk and between adjacent trees within the row. All rows were covered by polytunnels on 14 April 2014.

Experimental design

Two experiments were set up in the orchard using the West row of each double row, with five irrigation treatments per experiment. Irrigation in the Commercial Control (CC) treatment was applied to maintain the average ψ_m above -40 kPa throughout the season and Deficit Irrigation (DI) treatments of different duration and intensity were imposed during fruit growth Stages I, II and III, and postharvest.

Within each row, each experimental tree was separated by a guard tree. Each experiment was conducted in a completely randomised block design with six blocks of five plots; there were thirty experimental trees in total for each cultivar. All physiological measurements and record of yields of marketable fruit were conducted on the experimental tree.

To derive irrigation set points and to test the sensitivity of each growth stage to limited soil water availability, separate irrigation lines were installed for each of the four DI treatments in each cultivar. The frequency and duration of irrigation events to these plots was adjusted using Galcon irrigation controllers.

Measurement of soil matric potential and volumetric soil moisture content

Soil matric potential in each of the five treatments was monitored hourly from 12 April to 5 September 2014, using the similar equipment as described for the apple experiment. Probes were positioned 25 cm away from the North side of an experimental tree trunk and dripper. In both experiments, MPS2 probes 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, five ECRN rain gauges connected to EM50 data loggers were positioned directly below individual emitters within the CC and DI treatments of both experiments and downloaded weekly.

Commercial irrigation regime

Irrigation scheduling in the CC treatment was decided by EMR's Farm manager. Fertigation was applied for two hours daily until 7 July 2015, after which two hours of irrigation were applied each day until the end of August 2014. Three foliar feeds were applied, two in September and one in October. All trees were left unirrigated throughout the autumn and winter 2014-2015.

Irrigation scheduling in the DI treatments

Deficit irrigation treatments were imposed during fruit growth Stages I, II and III to determine whether growth stages were differentially sensitive to soil moisture deficits. During Stage I, the cell division phase, some cultivars are sensitive to limited soil water availability, whereas during Stage II, the pit-hardening phase, soil drying often has little effect on marketable yields. Soil moisture deficits during Stage III, the cell expansion phase, could limit fruit size

or increase the propensity for cracking in some cultivars. Irrigation was also withheld post-harvest to some trees to test the effects of soil moisture deficits during the flower initiation phase on cropping potential and fruit quality in the following year. When ITRs were not being implemented, all trees were irrigated to maintain soil ψ_m above -40kPa.

Fruit growth Stage I: In 'Merchant/Gisela 5', DI was first imposed on 17 April 2015, seven days after full bloom, for a total of 34 days. In 'Kordia/Gisela 5', DI was first imposed on 20 April 2015, eleven days after full bloom, for a total of 28 days.

Fruit growth Stage II: DI was applied on 20 May 2015 for seven days in 'Merchant/Gisela 5' and 15 days in 'Kordia/Gisela 5'.

Fruit growth Stage III: Irrigation was withheld from 'Merchant/Gisela 5' on 27 May 2015 until fruit were harvested on 18 June 2015. In 'Kordia/Gisela 5', DI was applied between 4 June and 25 June 2015, after which fruit were harvested.

Post harvest: Irrigation was withheld from 'Merchant/Gisela 5' from 18 June to 5 September 2015, for a total of 79 days. 'Kordia/Gisela 5' was unirrigated from 24 June to 5 September 2015, for a total of 73 days. Polytunnels were taken down on 4 August 2015 so both cultivars were not protected from rainfall from this date onwards,

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 between one to four hours throughout the growing season. Fertigation was applied at every irrigation event until early July, from then on foliar feeds were applied, as with the CC trees. From the beginning of September, all trees were unirrigated throughout the autumn and winter 2014-2015.

Physiological measurements

Tree physiological measurements were made three times each week, starting from when the first irrigation treatment was imposed and continuing until each cultivar was harvested in mid-late June. From then onwards, measurements were carried out once a week until the beginning of August when the polytunnel covers were removed. Measurements of stem and fruit growth were also made three times per week on each cultivar, beginning on 16 April

2015 and continuing until harvest. These measurements were carried out on all experimental trees to help detect differential sensitivities to limited soil water availability in each cultivar.

Stomatal conductance, rate of photosynthesis and midday stem water potential were measured as described for apple. 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 newly set fruit, each from a different fruit cluster on the same branch, from length and width measurements made with digital callipers. The relationship between ψ_{ms}, rate of fruit expansion and photosynthesis in trees exposed to drying soil was used to derive irrigation set points for testing in ITR treatments in 2015.

Fruit yield and quality

Fruit was harvested from 'Merchant/Gisela 5' trees on 18 June 2014 and from 'Kordia/Gisela 5' trees on 25 June 2014. Cherries were picked from the thirty experimental trees of each cultivar, and the total number and fresh weight of fruit from each tree was recorded. Yields were also 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 'good' fruit was selected at random to record the size variation for each tree, from 20 to 32 mm. 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 SSC with a digital refractometer.

Statistical analysis

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

Results

Apple

Return bloom

The CC, ITR and NI treatments applied in 2013 did not affect return bloom in either 'Gala/M9' or 'Braeburn/M9'. No significant differences were found in either the total number of blossom or when categorised into the type of bud; auxiliary, spur or terminal, with no effect of the previous year's irrigation treatments.

Effects of irrigation treatments on soil matric potential

'Gala/M9' or 'Braeburn/M.' trees under the CC treatment were irrigated to maintain the average soil ψ_{ms} above -40 kPa throughout the season (Figure 4A and B). In 'Gala/M9' trees under the ITR treatment, rainfall throughout the summer meant that average soil ψ_{ms} value

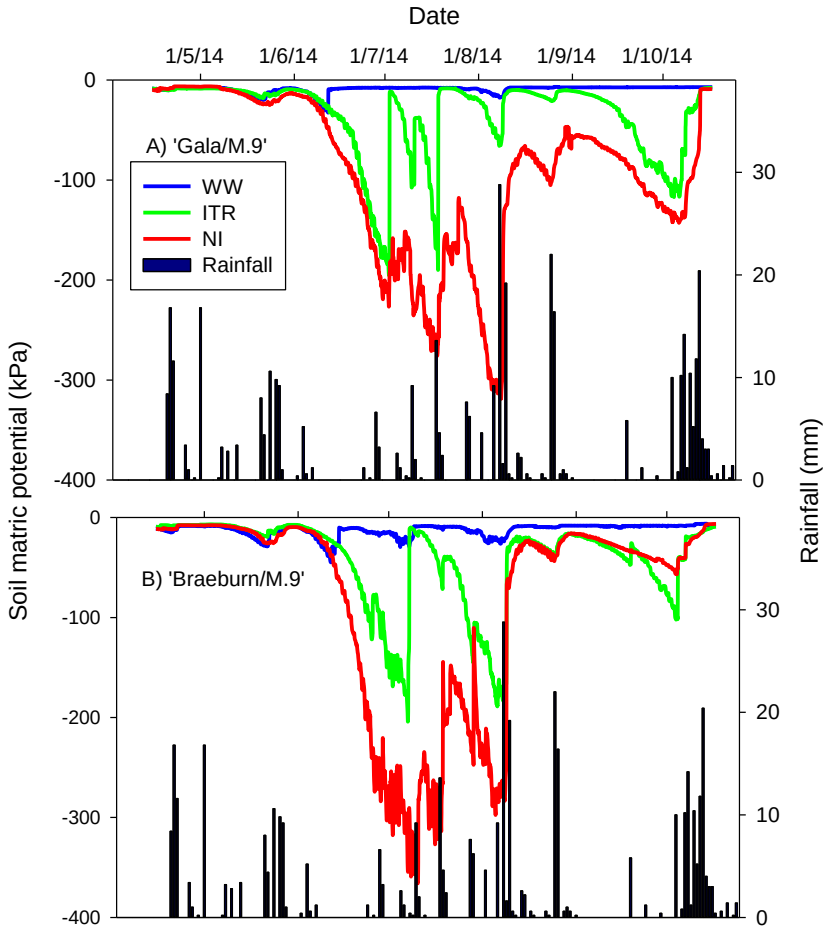

Figure 4. A) Changes in soil matric potential averaged over the top 60 cm of soil in each of the three irrigation treatments applied to 'Gala/M.9' trees in 2014. Rainfall throughout the experiment is also shown. B) Changes in soil matric potential at 20, 40 and 60 cm depth in 'Braeburn/M.9' trees under the three irrigation treatments.

fell to the -200 kPa set point on only two occasions during July 2014 (Figure 4A) at which point irrigation was applied to return the soil to near field capacity. Under the NI treatment, average soil ψ_{ms} values fell gradually until rainfall temporarily raised values in July, but then continued to fall to -330 kPa in early August until heavy rainfall raised values to -50 kPa in September. Following further moderate drying, soil was returned to field capacity in each of the three treatments following heavy and prolonged rainfall in mid-October (Figure 4A).

Similar changes in average soil ψ_{ms} were measured in 'Braeburn/M9' trees but the rate of soil drying in the ITR treatment was slower, and therefore only one irrigation event was applied at the set point of -200 kPa (Figure 4B). Under the NI treatment, a value of -355 kPa was reached in July and following several rain events, the average soil ψ_{ms} fell again to -288 kPa until the soil was returned to near field capacity in all treatments by heavy rainfall on 8-9 August 2015 (Figure 4B).

In both 'Gala/M9' and 'Braeburn/M9' trees, the volume of irrigation applied to the ITR trees was very much lower than those applied in the CC treatments (Table 1). Irrigation to the CC trees was applied for one hour daily until the end of October, in accordance with commercial practice at EMR.

Table 1. Volumes of irrigation water applied to 'Gala/M9' and 'Braeburn/M9 trees under the three irrigation treatments.

Variety	Volume of irrigation applied per tree (L)		
	CC	ITR	NI
'Gala/M9'	330	17	0
'Braeburn/M9'	337	14	0

Leaf physiological parameters

A fall in ψ_{ms} is one of the most sensitive physiological responses to limited soil water availability, and is often an indication that plants are experiencing a degree of water stress, The first indication that soil water availability was becoming limiting in 'Gala/M9' under the ITR and NI treatments was on 15 July 2014 when ψ_{ms} were significantly lower than values measured in the CC treatment. The average soil ψ_m at this time was -84 and -253 kPa in the ITR and NI treatments, respectively (Figure 5A). No other statistically significant differences in values of ψ_{ms}, g_s or photosynthesis were detected throughout cropping and the post-harvest period (data not shown).

In 'Braeburn/M9', ψ_{ms} became significantly lower in both the ITR and NI treatment when compared to the well-watered CC on 7 July 2015 when average soil ψ_m had reached -202 and -353 KPa, respectively (Figure 5B). Significant reductions in ψ_{ms} were also detected post-harvest on 5 August 2014 when ITR and NI treatments reached -178 and -297, respectively. No other statistically significant differences in values of ψ_{ms}, g_s or photosynthesis were detected throughout cropping and the post-harvest period (data not shown).

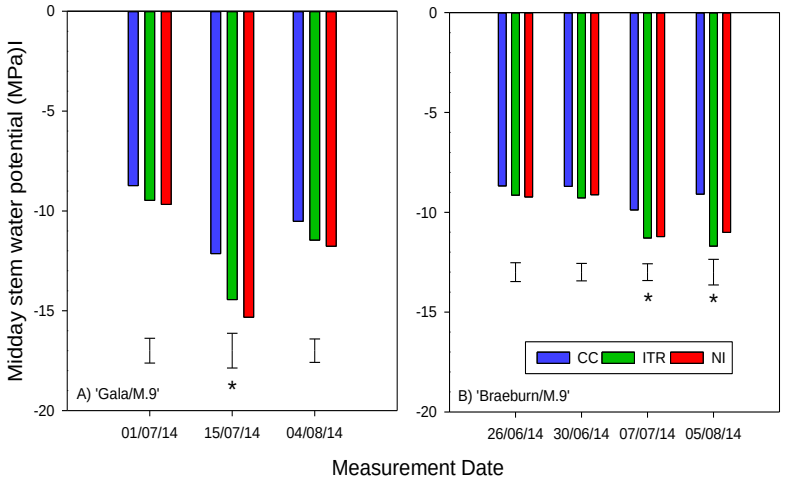

Figure 5. The effects of the three irrigation treatments on midday stem water potentials in A) 'Gala/M9' and B) 'Braeburn/M9' trees. Results are means of nine replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

Fruit growth

Fruit diameter and length were measured twice weekly and the effects of the irrigation treatments on cumulative FER were determined in the two cultivars. Cumulative fruit growth measured over two months in 'Gala/M9' was not significantly affected by either irrigation

treatment. In 'Braeburn/M9' where FER was measured over three months, there were several occasions when it was significantly reduced in the ITR and/or the NI treatments. The average soil ψ_m at these times was -23 and -57 kPa for the ITR treatment, and -298 kPa for the NI treatment. On 11 August 2014, the FER in both the ITR and NI treatments was reduced significantly at ψ_m values of -42 and -22 kPa; and again in the ITR treatment on 3 October 2014 at a ψ_m value of -90 kPa. On this last date however, FER in both the ITR and NI treatments was higher than in the CC treatment, even though the soil in all treatments was close to field capacity. On each occasion that differences in FER were detected, the leaf physiological parameters measured were similar in all treatments.

Fruit yields and size

The total yield, yield of Class 1, total fruit number and the number of Class 1 fruit from each 'Gala/M9' tree were not significantly affected by irrigation treatment (Figure 6A&B). Average fruit fresh weight was 96, 97 and 95 g from the CC, ITR and NI treatments, respectively, and these differences were not statistically significant. However, there was a significant increase

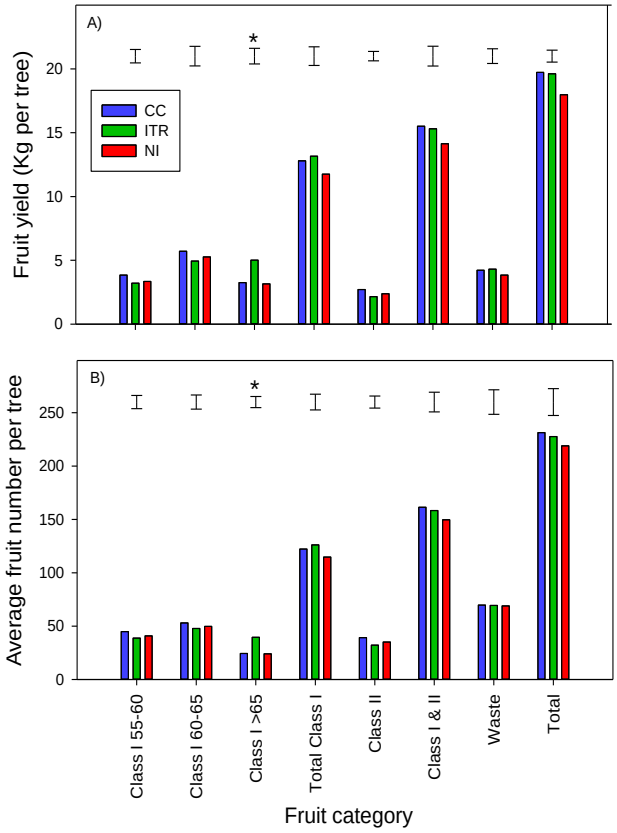

Figure 6. The effects of the three irrigation treatments on A) fruit yield and B) fruit number in 'Gala/M.9' trees. Results are means of nine replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

in the number and yield of fruit above 65 mm in the ITR treatment (Figure 6A and B). Total yields of cv. 'Gala' averaged 16 kg of fruit per tree in the CC treatment.

Average cv. 'Braeburn' fruit fresh weights from the CC, ITR and NI treatments were 160, 150 and 159 g respectively. Average fruit fresh weight from trees under the ITR treatment were significantly lower than that CC values; this was presumably due to higher Class II yields in the ITR treatment (Figure 7A and B). Despite this difference, the total yield, yield of Class 1, total fruit number and the number of Class 1 fruit from each 'Braeburn/M.9' tree were not significantly affected by irrigation treatment (Figure 7A and B). Total yields of 'Braeburn' averaged 13 kg of fruit per tree in the CC treatment.

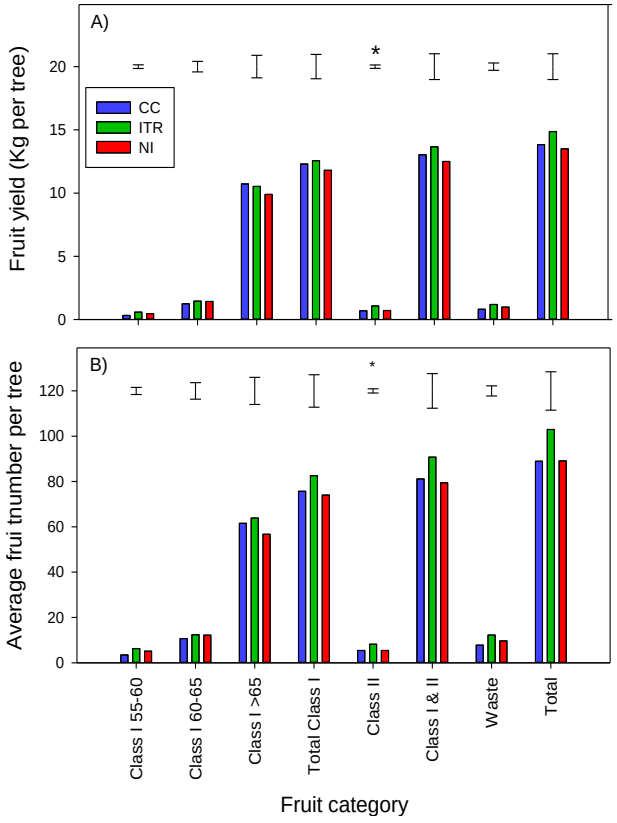

Figure 7. The effects of the three irrigation treatments on A) fruit yield and B) fruit number in 'Braeburn/M9' trees. Results are means of nine replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

Fruit quality components at harvest

Soluble solids content, fruit firmness and skin colour (parameters a, b and L) measured at harvest were not significantly affected by irrigation treatments in either cultivar (Table 2).

Table 2. Effects of the three irrigation treatments on fruit quality components at harvest in cvs. 'Gala and 'Braeburn'.

Treatment	'Braeburn'		Colour			'Gala'		Colour		
	SSC	Firmness at 8mm (N)	a	b	L	SSC	Firmness at 8mm (N)	a	b	L
CC	11.4	83.0	14.1	31.6	47.9	11.2	85.7	22.7	27.5	52.2
ITR	11.6	84.6	13.5	32.2	49.3	11.3	83.2	21.9	27.9	53.0
NI	11.7	83.1	16.2	31.2	47.5	11.4	84.7	22.3	28.5	53.7
F-value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD	0.36	2.08	3.13	1.43	2.22	0.54	2.47	3.66	1.31	2.36

Sweet cherry

Irrigation treatments

'Kordia/Gisela 5' and 'Merchant/Gisela 5' trees under the CC treatment were irrigated to maintain the average soil ψ_m above -40 kPa throughout the season (Figure 8A and B). However, at certain points and at certain growth stages the average soil ψ_m fell dropped below -40 kPa, despite increased duration of irrigation events.

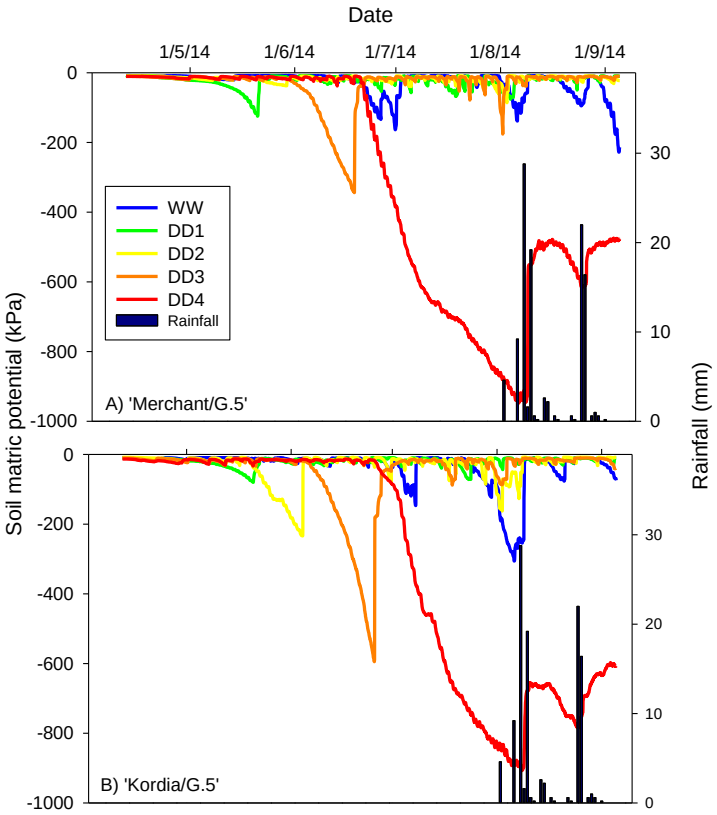

Figure 8. A) Changes in soil matric potential averaged over the top 60 cm of soil in each of the five irrigation treatments applied to 'Merchant/Gisela 5' trees in 2014. Rainfall throughout the experiment is also shown. B) Changes in soil matric potential at 20, 40 and 60 cm depth in ''Kordia/Gisela 5' trees under the three irrigation treatments.

In 'Kordia.Gisela 5', average soil ψ_m reached values of -65, -218, -581 and -900 kPa during stages I, II, III and post-harvest, respectively. In 'Merchant/Gisela 5', average soil ψ_m values fell to -115, -36, -332 and -925 kPa during the four deficit irrigation treatments.

Leaf physiological parameters

Measurements of g_s, ψ_{ms} and photosynthesis were carried out three times per week on each cultivar in each of the five irrigation treatments. In 'Merchant/Gisela 5 under the ITR treatments, values of ψ_{ms} were temporarily but significantly lower than CC values on 30 June 2014 during the post-harvest stage when average soil ψ_m reached -358 kPa (Figure 9A and B). Significant and sustained differences in ψ_{ms} between the CC and ITR treatments were detected from 21 July 2014 (Figure 9A) when average soil ψ_m reached -727 kPa and continued to fall to -923 kPa on 4 August 2014. Photosynthesis in 'Merchant/Gisela 5' was also significantly lowered in the ITR treatment compared to CC values on 14 July 2014, when average soil ψ_m reached -679 kPa (data not shown).

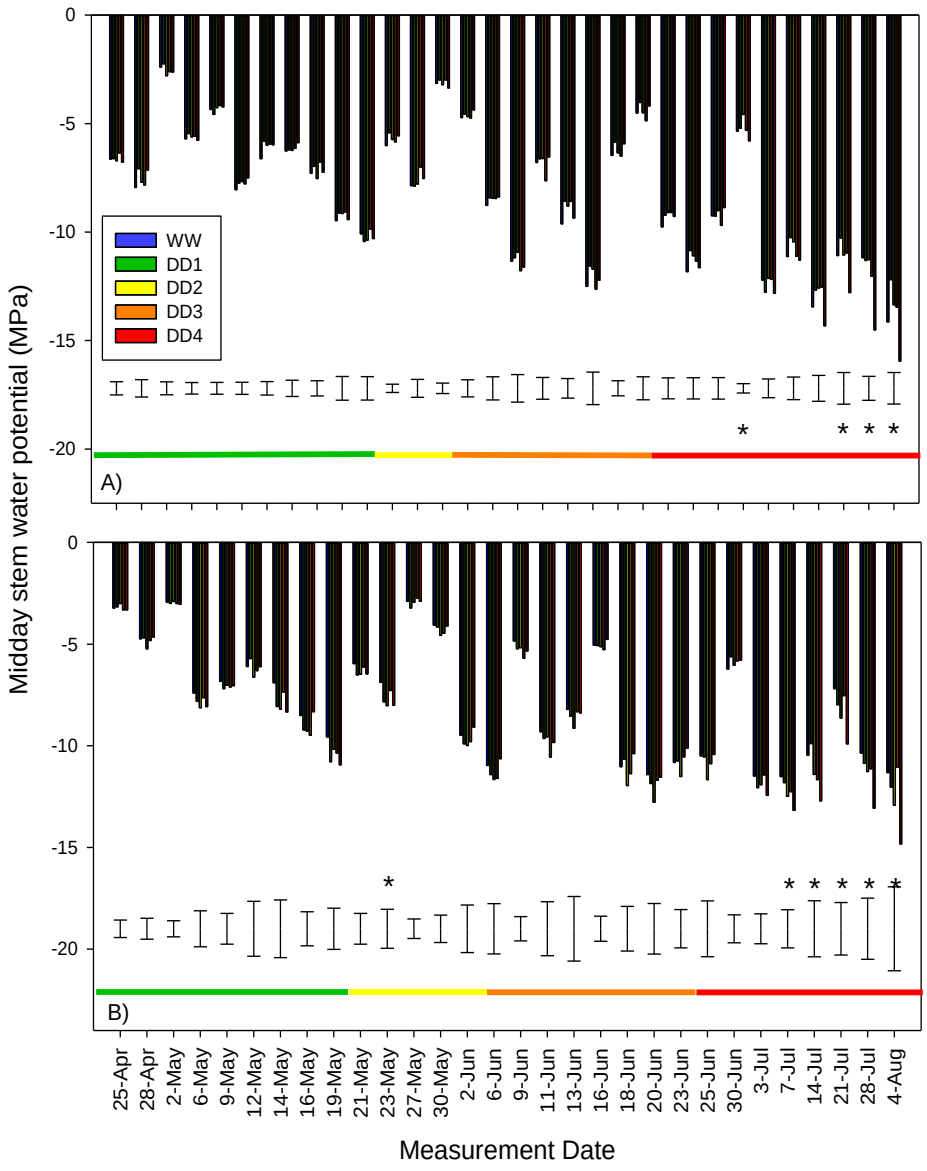

Figure 9 The effects of the three irrigation treatments on midday stem water potentials in A) 'Merchant/Gisela 5' and B) 'Kordia/Gisela 5' trees. Results are means of nine replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by asterisks.

During the ITR treatment applied to 'Kordia.Gisela 5' during Stage II, ψ_{ms} was temporarily but significantly reduced on 23 May 2014 (Figure 6B) at a soil ψ_m of -63 kPa. In the post-harvest ITR treatment, ψ_{ms} values were significantly lower than CC values from 7 July - 4 August 2015 when average soil ψ_m ranged from -330 to -881 kPa. No consistent treatments effects on leaf physiological parameters were detected in 'Kordia/Gisela 5'.

Fruit and shoot growth

Fruit diameter and length were measured three times a week during each of ITR treatments applied during Stages I, II and III. In both 'Merchant/Gisela 5' and 'Kordia/Gisela 5', cumulative fruit growth and FER measured over the ten week cropping period were not significantly affected by the irrigation treatments (data not shown).

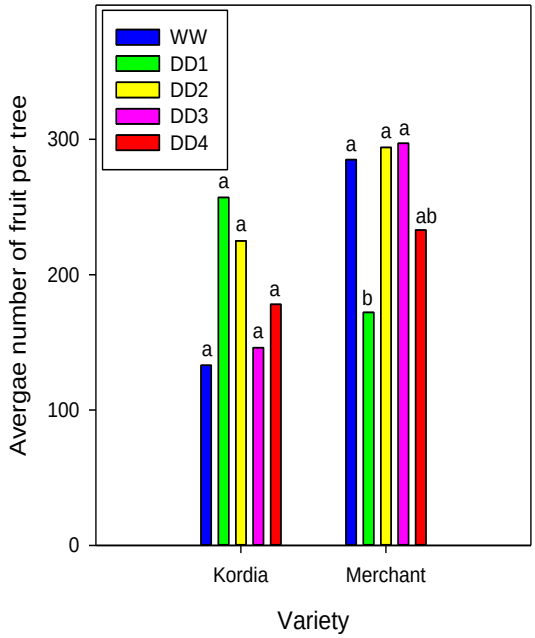

Figure 10. The effects of the five irrigation treatments on the average fruit number per tree for 'Merchant/Gisela 5' and 'Kordia/Gisela 5' trees. Results are means of nine replicate trees. Vertical bars are LSD values at $p<0.05$; significant differences between treatments are indicated by different letters.

Shoot lengths were measured three times a week throughout all ITR treatments to determine the effects of the soil moisture deficits on rates of shoot extension. In 'Merchant/Gisela 5' in the Stage III ITR treatment, there was a significant increase in cumulative shoot growth on five out of eight measurement dates, compared to WW values (data not shown). Shoot growth was not significantly affected by irrigation treatments in 'Kordia/Gisela 5'.

Fruit yield and size

Total yields of cv. 'Merchant' from the CC and ITR treatments applied during Stages I, II, and III were 2.98, 2.02, 2.98, and 3.16 Kg per tree, respectively. The ITR treatment applied during Stage I reduced marketable yield significantly, compared to CC values (Figure 7), this was due to an effect on fruit number; average fruit weight was unaffected.

Total yields for cv. 'Kordia' from the CC and ITR treatments applied during Stages I, II, and III were 1.83, 3.21, 2.82, and 1.59 Kg, respectively, and these differences were not statistically significant. There were no significant differences in total fruit number, average fruit fresh weight or size (data not shown).

Fruit quality at harvest

There were no significant treatments effects on fruit cracking, rots or any other disorders in either cultivar. The application of the ITR to 'Merchant/Gisela 5' trees during Stage III resulted in a significantly lower SSC (17.4) compared to CC values (18.3); SSC was unaffected by ITRs applied during Stages I and II. Fruit firmness and the distribution of fruit amongst the different size classes were unaffected by irrigation treatment (data not shown).

In cv. 'Kordia', SSC was not significantly affected by imposing soil moisture deficits during any fruit growth stage, compared with the CC treatment (Table 3). Soil water deficits applied during growth Stages II and III led to a significant reduction in fruit firmness when compared to CC values. The distribution of fruit amongst the different size classes was not affected by irrigation treatment (Table 3).

Table 3. Effects of the five irrigation treatments on cv. 'Kordia' fruit quality components at harvest.

Treatment	SSC	Firmness at 8mm (N)	Number of fruit in each size category (mm)						
			20	22	24	26	28	30	32
CC	16.9	339.3	0.0	0.0	1.3	7.8	22.8	17.0	1.0
DD1	17.3	312.2	0.0	0.2	6.3	6.3	21.0	15.2	0.7
DD2	17.0	290.9	0.0	0.2	8.8	8.8	28.0	11.0	0.8
DD3	17.6	287.7	0.0	0.5	5.7	5.7	23.3	12.3	0.3
DD4	16.0	303.4	0.0	0.3	4.8	4.8	25.0	18.7	0.8
F-value	0.03	0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD	0.94	30.17	0.0	0.6	1.6	5.8	8.0	11.0	1.5

Discussion

One aim of the work in the second year was to try to identify the point at which soil moisture availability begins to limit fruit size and marketable yields in 'Gala/M9' and 'Braeburn/M9'. Average soil ψ_m in the top 60 cm of soil fell to -310 kPa on 8 August 2014, and although this resulted in significant reductions in midday stem water potentials and rates of photosynthesis, 'Gala/M9' and 'Braeburn/M9' Class 1 yield and number were not affected. The frequent rainfall during 2014 meant that is was not possible to identify the ψ_{ms} at which fruit expansion rate and photosynthesis in the two apple varieties were consistently reduced. Nevertheless, the data have helped to inform the development of a conservative water-saving irrigation strategy for commercial cvs. 'Gala' and 'Braeburn' production that limits water and fertiliser losses without jeopardising marketable yields and quality (see below).

The accumulated evapotranspiration over the season in the Concept Pear Orchard at EMR was 446 mm, and 397 mm of rainfall fell between April and October. 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 cvs. '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. Furthermore, adopting this approach will increase leaching of N and other nutrients past the rooting zone (see Annual Report for TF 214). It should be noted that a similar degree of soil moisture deficit experienced at a different stage during cropping could affect marketable yields and/or quality.

A second aim of our work in 2014 was to test whether adopting an irrigation set point of -200 kPa (matric potential averaged throughout the rooting zone) could be used to optimise both on-farm water use efficiency and crop productivity. Our results suggest that significant water and fertiliser savings could be achieved using a lower irrigation set point of -200 kPa without affecting yields or quality. Further work is now needed to test this water-saving irrigation strategy on commercial cvs. '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 the water-saving strategy to monitor crop health and performance under these low-input growing systems.

The aim of the work with sweet cherry 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. The approach was to impose temporary and gradual soil drying at each stage of fruit growth so that the average soil ψ_m within the rooting zone at which tree physiology is first affected could be identified. Irrigation treatments were applied during fruit growth stages I (cell division), II (pit hardening) or III (fruit expansion) to determine whether sensitivity to soil moisture deficits was influenced by fruit developmental stage. The effects of soil drying imposed after harvest on fruit set, cropping potential and quality in the subsequent year was also investigated.

In 'Kordia/Gisela 5', average soil ψ_m 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 cv. '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 ψ_m fell beyond -350 kPa and the effects of this treatment on return bloom, Class 1 yields and fruit quality will be determined in cv. 'Kordia' in 2015.

In 'Merchant/Gisela 5', average soil ψ_m 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 2015, average soil ψ_m will be maintained above -60 kPa during Stages I and II, and above -200 kPa during stage III in each of the two cultivars, and the effects on Class 1 yields will be compared with those from CC trees. The effects of soil moisture deficits during the flower initiation phase (the post-harvest treatment) in 2014 on yields and quality of cvs. 'Kordia' and 'Merchant' Class 1 fruit in 2015 will be determined.

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 cultivar to drying soil in the top 60 cm. The soil ψ_m at 60 cm fell to -100 kPa in early August in 'Braeburn/M9' 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. Nevertheless, we will use Delta-T profile probes to monitor changes in soil volumetric moisture content at 10 cm intervals in the top 1 m of soil in our experiments with sweet cherry in 2015 to provide detail on water uptake from different soil horizons throughout the growing season.

Conclusions

Apple

- ‘Gala/M9’ 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/M9’ Class 1 yield and number were not affected.
- ‘Braeburn/M9’ 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 cv. ‘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 cv. ‘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 cvs. ‘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 cv. ‘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 and the effects of this treatment on return bloom, Class 1 yields and fruit quality will be determined in cv. ‘Kordia’ in 2015.
- 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 2015, soil matric potential will be maintained above -60 kPa during Stages I and II, and above -200 kPa during stage III in each of the two cultivars, and the effects on Class 1 yields will be compared with those from CC trees.
- The effects of soil moisture deficits during the flower initiation phase (the post-harvest treatment) in 2014 on yields and quality of cvs. 'Kordia' and 'Merchant' Class 1 fruit in 2015 will be determined.

Knowledge Exchange and Technology Transfer activities

- Results were included in a presentation 'Sustainable irrigation of high-intensity tree fruit orchards', made at the EMRA/AHDB Horticulture Tree Fruit Day, EMR, 24 April 2014
- The project aims, objectives and results were presented to the West Sussex Fruit Group, EMR, 29 July 2014
- Results were included in a presentation 'Improving food chain resilience, quality and security' made to the Agro-Cleantech Cluster, 8 December 2014
- Results were included in a presentation 'Improving resource use efficiency, yields and quality of fresh produce' at the Waitrose Science Day, University of Warwick, 25 February 2015
- The project aims, objectives and results were presented at the AHDB Horticulture Tree Fruit Agronomists' Day, EMR, 26 March 2015
- An article summarising project results from 2014 was prepared for the AHDB Horticulture Tree Fruit Review

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