Project title:	Impact of irrigation practices on Rijnsburger bulb onion husbandry, quality and storability - II
Project number:	FV 326a
Project leader:	Dr. Tim Lacey, Vegetable Consultancy Services (Developments) Ltd.
Report:	Annual report, Year 3
Previous report:	None
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Date project completed (or expected completion date):	30th September 2013

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

Grower Summary **1**
Headline 1
Background 1
Summary 1
Financial Benefits 6
Action Points 6
Science Section **7**
Introduction 7
Materials and methods 8
Experimental design and layout 8
Weather / soil moisture monitoring and irrigation scheduling 12
Crop performance 12
Crop pest and disease 13
Soil nitrate leaching 13
Weed response 14
Irrigation efficiency, cost-benefit and identifying optimal irrigation regimes 14
Statistical analysis 14
Results 15
Weather / soil moisture monitoring and irrigation scheduling - 2012 15
Crop performance - 2012 21
Crop storage – 2011 27
Crop pest and disease - 2012 29
Soil nitrate leaching - 2012 30
Weed response - 2012 32
Irrigation efficiency, cost-benefit and identifying optimal irrigation regimes – 2012 32
Discussion 33
Conclusions 36
Knowledge and Technology Transfer 37

The authors would like to acknowledge the invaluable assistance of RL Long Farms Ltd. in accommodating the open-field trial within their commercial onion land. Thanks also to Wroot Water and Pessl Instruments for their assistance in the technical aspects of trial operation.

GROWER SUMMARY

Headline

This project is aiming to provide best practice irrigation guidelines to increase the yield and quality of onions

Background

An estimated 85% of dry bulb onion crops in the UK are irrigated, following a drive in the industry for production on light soils to improve quality and aid crop management. There are however, concerns that existing irrigation practices may be compromising crop yield, quality and storability. Furthermore, there is little scientific evidence to support current practices, either for crop production or to justify irrigation water use and demonstrate efficiency for abstraction licence renewal in the future.

This project builds on findings from a 1-year HDC trial FV 326 (2007-8), which strongly indicated that irrigation practices had a significant impact on crop performance. Due to inherent limitations of FV 326, further, large-scale field-based trials were required to fully evaluate the impact of irrigation regimes, particularly on crop quality and storability. This follow-on project proposes to address these issues by extending the original study to one commercial-scale field trial plus one rain-shelter trial over a period of 3 seasons.

Ultimately, this project will identify optimum, “best-practice” irrigation guidelines, designed to help growers maximise marketable percentages and increase the storage period of bulb onions. Furthermore, the findings will assist growers at abstraction licence renewal and may show benefits for nutrient and weed management.

This report summarises the available data for year 3 of the trial (2012 season) and also presents the storage data from 2011. Note that all other data from 2011 and 2010 were reported in the year 1 and year 2 annual reports.

Summary

- Irrigating with “little and often” up to bulb initiation tends to increase bulb onion canopy growth, biomass and yield, but may encourage bolting.

- Water stress in the period up to bulb initiation can reduce crop yield potential by up to 30%.

- More frequent overhead irrigation and/or rainfall events appear to reduce onion thrip damage, but may increase disease risk (especially downy mildew), nitrate leaching and weed flushes.

- Conclusions on whether irrigation regimes can adversely affect onion bulb quality cannot be drawn until storage trials have been completed.

A description of the irrigation regimes applied at the rain-shelter site and the open-field commercial site is given in Table 1. Treatment A represents typical field practice for bulb onion irrigation. Both sites were on sandy loam near Bury St Edmunds.

The open-field site received frequent rain, including heavy showers, from early April through to harvest (with the exception of short periods at the end of May and during September). Consequently, few irrigation events were scheduled on this site, and little differences between treatments were observed. Therefore, most data observations relate to the rain-shelter site only in this summary.

Table 1 Irrigation regimes investigated in 2012.

Trt	Name	L May to Initiation (E July)		Initiation (E July) to egg stage (E Aug)		Egg stage (E Aug) to stop (50% FO)		Stop
		Trigger	Target App^n	Trigger	Target App^n	Trigger	Target App^n	
A	Typical, end season stress	50% AWC	Return to FC	50% AWC	Return to FC	75% AWC	50% of AWC	50% FO
B	Typical with mid+end season stress	50% AWC	Return to FC	75% AWC	50% of AWC	75% AWC	50% of AWC	50% FO
C	Typical with early+end season stress	75% AWC	50% of AWC	50% AWC	Return to FC	75% AWC	50% of AWC	50% FO
D	Less more often, no stress	25% AWC	Return to FC	25% AWC	Return to FC	25% AWC	Return to FC	50% FO
E	Less more often, end season stress	25% AWC	Return to FC	25% AWC	Return to FC	75% AWC	50% of AWC	50% FO
F	Less more often, end season stress irrigation at 100% FO	25% AWC	Return to FC	25% AWC	Return to FC	75% AWC	50% of AWC	50% FO but 10mm @ 2 days before harvest
G	Less more often early season, typical mid season, end season stress	25% AWC	Return to FC	50% AWC	Return to FC	*75% AWC*	50% of AWC	50% FO
H	Stress all season	75% AWC	50% of AWC	75% AWC	50% of AWC	75% AWC	50% of AWC	50% FO

AWC = Available Water Content within rooting zone (assumed to be 30cm)
FC = Field Capacity within rooting zone (assumed to be 30cm)
FO = canopy fall-over

At the rain-shelter site, crop growth and vigour was significantly influenced by the irrigation regime applied (see Figure 1). Irrigation regimes that applied "less more often" achieved a larger canopy with greater biomass quicker than regimes that applied less water or with less frequent irrigations. In particular, regimes that maintained low soil moisture deficits early in the season (up to bulb initiation) promoted the greatest canopy growth and those with early season stress significantly reduced canopy growth rate and overall potential.

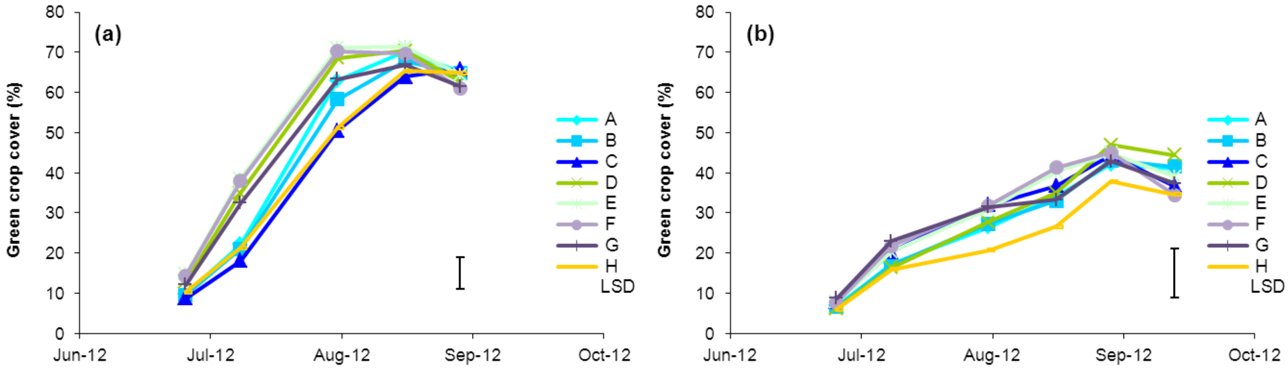

Figure 1 Crop canopy growth as % green cover at rain-shelter site (a) and open-field site (b). Error bars show least significant difference (LSD).

The differences in crop canopy translated into significant differences in green crop yield (Figure 2). Water stress early in the season (up to bulb initiation) significantly reduced green yields in "typical" type regimes by 13% (up to a 30% reduction was observed in 2011). Irrigating through to 50% fall-over produced a further yield increase of 13% over a regime with the standard practice of imposing water stress at the end of the season. Contrary to 2010 and 2011 trials, "little and often" regimes in 2012 resulted in slightly lower green yields when compared to equivalent "typical" regimes.

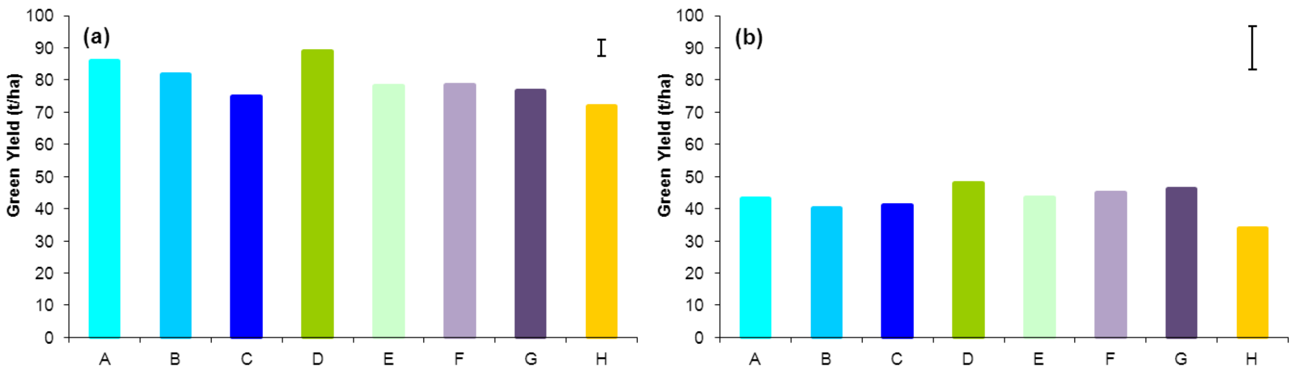

Figure 2 Crop green yield at rain-shelter site (a) and open-field site (b). Error bars show LSD.

Preliminary work on 2010, 2011 and 2012 data shows a strong relationship between total water received by an onion crop (up to c300mm) and green yield, resulting in a yield increase of approximately 0.25-0.3 tonnes/ha per mm. Beyond a total water input of 300mm, the relationship tends to plateau and perhaps decrease. The nature of this relationship requires further investigation and will be reported in greater detail in the final report.

Onions harvested for green yield in 2012 are currently in storage under commercial conditions to be assessed for quality and marketability (including size, skin finish, shape, doubles, disease, regrowth and dry matter content) in April/May 2013.

Storage data from 2011 closely reflected the green yield described in the year 1 report (January 2012). Size grading indicated that the irrigation regimes which promoted the greatest crop growth and green yield tended to have a greater proportion of larger bulbs and fewer smaller bulbs. Contrary to expectations (but reflecting 2010 season results), quality assessments indicated that there were few differences in storage diseases, dry matter, regrowth and other defects resulting from the irrigation treatments applied.

Although thrip levels were much lower than previous years, observations at the rain-shelter site continue to support the assertion that overhead irrigation assists in onion thrip control. There was some indication that regimes with frequent applications during mid or late season could increase the incidence of downy mildew, but other diseases (leaf blight, leaf spot and bacterial infections) appeared to be largely unaffected.

There was some indication that irrigation regimes which applied water earlier and/or had more frequent irrigations may retain less N in the soil than current practice or “stress” irrigation Soil ammonium N and nitrate data were however highly variable so definitive conclusions cannot be drawn at this time.

Weed pressure was generally higher where irrigation regimes kept the soil surface moist (i.e. more frequent irrigations), but the effect of rainfall, grower intervention and timing of water application are likely to be more important than the irrigation regime when managing weed burden.

In summary, data from the third year of trials support the 2010 and 2011 data from FV326a and previous FV 326 findings (despite the poor weather on the open-field site). Onions respond well to water, with more frequent applications of smaller amounts tending to drive canopy development, crop vigour and biomass more than typical applications of c25mm every 7-10 days. In particular, early season irrigation (prior to bulb initiation) appears key to driving crop development. Some caution does however need to be applied to prevent excess canopy developing too early, thus increasing the bolting risk. Increased canopy development largely translates into greater yield, although late application of water also tends to increase yields, most likely due to direct water uptake by the bulb. At the time of this report, crop quality and storability from 2012 have not been assessed. Indications from 2010 and 2011 storage assessments were that different irrigation regimes did not affect storability; however, this is largely contrary to commercial experience.

Financial Benefits

No indication of financial benefits can be given until all data from the 3-year trial has been collected and analysed. This will be presented in the final project report.

Action Points

At this stage of the project, it is not advised that growers make any extensive changes to their irrigation regimes based on the information contained in this report: further data is required on crop quality and marketability and all results require analysis collectively to support any changes in irrigation practice. It is, however, becoming relatively clear that growers should consider prioritising the irrigation of their onions in the early season to promote canopy, at least up to the point of bulb initiation – bearing in mind the potential for increased bolting in excessively forward crops.

SCIENCE SECTION

Introduction

Cured and stored Rijnsburger dry bulb onions (*Allium cepa*) form a significant proportion of the UK vegetable sector. An estimated 85% of the crop is irrigated.

There are concerns that existing irrigation practices may be compromising crop yield, quality and storability. Furthermore, there is little scientific evidence to support current practices, either with respect to agronomic aims or to justify irrigation water use and demonstrate efficiency for abstraction licence renewal in the future.

To this end, project FV 326a was established to continue the successful FV 326 onion irrigation trial of 2007/8. FV 326 was a 1-year trial that demonstrated significant differences in crop production as a result of differing irrigation regimes under rain-shelter conditions. However, due to inherent limitations, further, large-scale field-based trials were required to fully evaluate the impact of irrigation regimes, particularly on crop quality and storability. This follow-on project proposes to address these issues by extending the original study to one commercial-scale field trial plus one rain-shelter trial over a period of 3 seasons.

Project FV 326a proposes to investigate a range of irrigation regimes (based on FV326 and industry consultation) in each of the 3 years of the work for their impact on bulb onion crop growth, yield, quality and storability and for the secondary impacts on nitrate leaching and weed flushes. Ultimately, the trial results will lead to the identification of optimum irrigation practices in the form of "best-practice" guidelines to help growers maximise marketable percentages and increase the storage period of bulb onions, thereby increasing profitability. Furthermore, the findings will assist growers at abstraction licence renewal and may potentially show benefits for nutrient and weed management.

Year 1 of FV326a (2010) demonstrated that different irrigation regimes resulted in significant differences in crop growth and yield. "Little and often" type regimes tended to drive greatest canopy growth, thus promoting yield. Late applied water also tended to bulk up yields. However, contrary to expectations, little difference in disease levels and overall storability was noted between treatments.

Year 2 results substantiated year 1 findings and also highlighted the importance of early season irrigation in building crop canopy and ultimately crop yield. Again, late applied water tended to bulk up yields, believed to be as a result of direct water uptake.

This report summarises the trials carried out in Year 3 of the project (2012/13 – referred to as 2012 season in this report) and reports available data from this work. Note that not all data for this year is currently available, since harvested bulb onions are being stored until March/April for assessment of crop quality and storability attributes. This report also summarises post-storage size grading and quality data from the 2011 trial.

Materials and methods

Experimental design and layout

The project again comprised two parallel experiments in Year 3: at one site, a bulb onion crop was grown under artificial rain-shelters and exposed to a range of differing irrigation regimes; at a second site, the same irrigation regimes were applied on a site located within a commercial onion field. The rain-shelter site was hosted by Broom's Barn Research Centre (near Bury St Edmunds, Suffolk) and the open-field site was hosted by RL & JP Long (also near Bury St Edmunds) (See Figure 3) For the purposes of this report, the sites will be referred to as "rain-shelter" and "open-field" respectively. Details of each site are presented in Table 2

Figure 3 Field site locations 2012

Table 2. Details of rain-shelter and open-field sites

	Rain-shelter	**Open-field**
Soil type	Sandy loam	Sandy loam
Onion variety	Arthur	Arthur
Drilling date	20th March	29th February
Target density	52 plants per m^2	48 plants per m^2
Wheel centres	1.83m	1.83m
Plot size	1 bed by 8m	3 beds by 10m
No. of sprinklers per plot	8	16
Replicates	3	3
Irrigation treatments	8	8
Date of wetting to field capacity (FC)	13th May (rain only)	13th May (rain only)
Harvest date	14th and 21st September	19th September
Crop husbandry	As field crops (except water)	As rest of field (except water)

Each site had three replicate blocks of eight differing irrigation regimes, as described in Table 3. These irrigation regimes were chosen based on results from FV 326 and industry advice. Treatment A represents typical field practice on light mineral soils.

Plot layout at each site is presented in Figure 4 and Figure 5 while Figure 6 and Figure 7 illustrate the two sites.

Table 3 Irrigation regimes

Trt	Name	L May to Initiation (E July)		Initiation (E July) to egg stage (E Aug)		Egg stage (E Aug) to stop (50% FO)		Stop
		Trigger	Target App^{n}	Trigger	Target App^{n}	Trigger	Target App^{n}	
A	**Typical, end season stress**	50% AWC	Return to FC	50% AWC	Return to FC	75% AWC	50% of AWC	50% FO
B	**Typical with mid+end season stress**	50% AWC	Return to FC	75% AWC	50% of AWC	75% AWC	50% of AWC	50% FO
C	**Typical with early+end season stress**	75% AWC	50% of AWC	50% AWC	Return to FC	75% AWC	50% of AWC	50% FO
D	**Less more often, no stress**	25% AWC	Return to FC	25% AWC	Return to FC	25% AWC	Return to FC	50% FO
E	**Less more often, end season stress**	25% AWC	Return to FC	25% AWC	Return to FC	75% AWC	50% of AWC	50% FO
F	**Less more often, end season stress irrigation at 100% FO**	25% AWC	Return to FC	25% AWC	Return to FC	75% AWC	50% of AWC	50% FO but 10mm @ 2 days before harvest
G	**Less more often early season, typical mid season, end season stress**	25% AWC	Return to FC	50% AWC	Return to FC	*75% AWC*	50% of AWC	50% FO
H	**Stress all season**	75% AWC	50% of AWC	75% AWC	50% of AWC	75% AWC	50% of AWC	50% FO

AWC = Available Water Content within rooting zone (assumed to be 30cm)
FC = Field Capacity within rooting zone (assumed to be 30cm)
FO = canopy fall-over

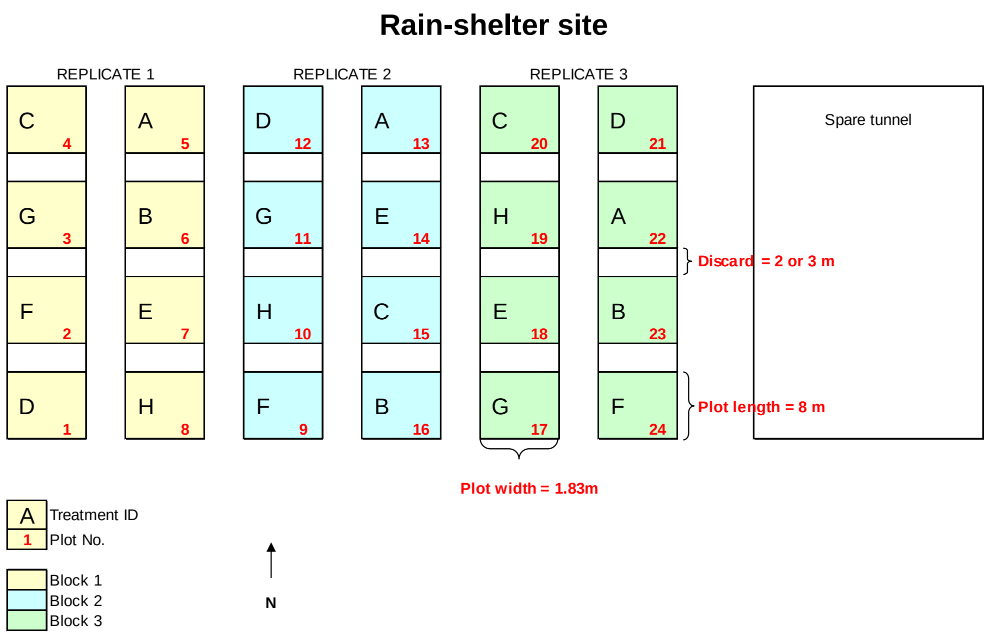

Figure 4. Plot layout at rain-shelter site

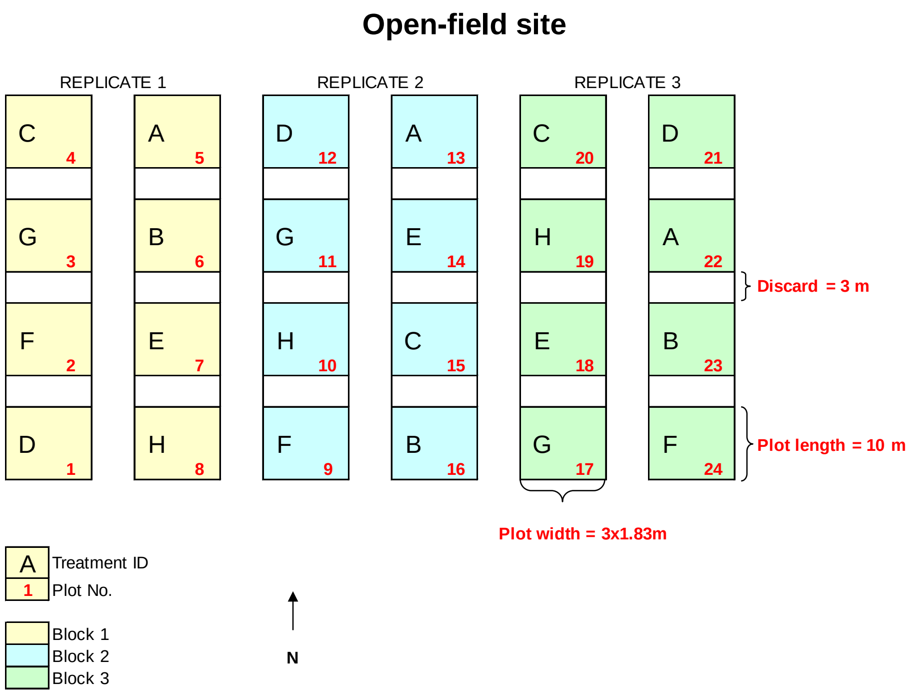

Figure 5. Plot layout at open-field site.

Figure 6. Rain-shelter site (replicate 1) on 11th July 2012.

Figure 7. Open-field site (replicate 1) on 7th July 2012

Weather / soil moisture monitoring and irrigation scheduling

Irrigation events were scheduled using calculations of soil moisture deficit based on data from soil moisture sensors in each plot (3x Decagon 10HS sensors per plot at 10, 20 and 30cm depths). All sensors were connected to an iMetos weather station, with all data (including weather data at each site) downloading to a secure web-site. Both sites were at field capacity near the start of the season (due to rain) and this allowed accurate determination of soil moisture deficit. At each irrigation event, rainguages were placed in each plot to verify the amount of irrigation applied.

Crop performance

The impact of irrigation regimes on crop performance was evaluated using a number of parameters as detailed below.

Crop establishment was measured using 3 randomly placed replicate counts of bulbs harvested from a 1 m section of bed.

Crop canopy growth was measured approximately weekly through the season using a spectral ratio meter (Skye Spectrosense 2) to determine % green cover at a specific point in each plot. Crop vigour was assessed visually at approximately fortnightly intervals (on a scale of 0= dead to 10= extremely vigorous). At approximately 4-week intervals, crop biomass was assessed by weighing a sub-sample of 10 randomly selected plants per plot.

As the crop neared maturity, fall-over progression was noted (as % fall-over and % senescence). At harvest (14th and 21st September at rain-shelter site and 19th September at open-field site) 3 randomly placed replicate samples of 1 m x 1 bed were hand harvested (with tops removed), counted for population data, netted and weighted to assess green bulb yield. All samples were then placed in a commercial onion store for further assessments after curing and storage (size grading, disease and physiological defects, dry matter). 2011 samples were assessed between the 2nd May 2012 (rain-shelter) and 20th June 2012 (open field). From each plot at the rain-shelter site only, a random sub-sample of bulbs were taken and amalgamated by treatment to a single sample for analysis of quality and storability bio-markers. Note that it had originally been intended to analyse a sample from each plot from both sites for these markers, but the extremely high cost of analysis proved prohibitive.

Observations in 2011 indicated that there may have been some differences in the proportion of plants “bolting” (prematurely flowering) between treatments. Consequently, although it was not originally programmed for assessment, counts of the number of bolting plants per plot were made prior to harvest. Counts were converted into a % bolting using the average plant population counts from each plot.

Post-storage assessments will take place after long-term storage (approximately April/May 2013). All netted samples will be assessed for dried bulb yield, bulb size, bulb quality (including skin quality, bulb morphology, disease etc.) and marketable yield. In addition, a sub-sample of bulbs will be tested for dry matter content.

Crop pest and disease

Crop pest and disease incidence and severity was visually assessed for: onion thrips (*Thrips tabaci*); downy mildew (*Peronospora destructor*); leaf blight (*Botrytis squamosa*); leaf blotch (*Cladosporium allii* / *C. allii-cepae*); secondary bacterial infection on foliage, and; bacterial rots in bulbs. Note that crop pest and disease data were not subjected to statistical analysis since this was intended as a solely observational part of the experiment. Observations were made on a scale of 0 = no infection/infestation to 10 = extreme infection/infestation.

Soil nitrate leaching

The impact of irrigation regimes on nitrate leaching from the soil was evaluated by assessment of soil mineral nitrogen (as nitrate and ammonium) at the start (immediately prior to commencing irrigation), middle and end of the season. Multiple samples were taken from each plot at 0-30cm and 30-60cm and amalgamated to a single sample for each depth. The rain-shelter site was sampled on the 9th May (start), 1st Aug (mid) and 14th September (end). The open-field site was sampled on the 16th May, 6th August and 18th September. Samples were kept cool and sent for analysis at Anglian Soil Analysis Ltd.

Weed response

Weed response to irrigation regimes was monitored by visual assessment of weed levels prior to harvest (on a scale of 0 = no weeds to 10 = extreme weed pressure). Data were recorded on 14th September at the rain-shelter site and 19th September at the open-field site.

Irrigation efficiency, cost-benefit and identifying optimal irrigation regimes

Data collected from trials to date will be used in combination with crop quality information after storage to calculate the irrigation efficiency of the tested regimes and to conduct a cost-benefit analysis in the final report. This information will assist in identifying an optimal irrigation regime for bulb onions, ultimately helping to justify water use and demonstrate efficient irrigation to the Environment Agency for irrigation licence renewal in the future.

Statistical analysis

All data were subject to statistical analysis by the biometric department at Rothamsted Research. Analysis of variance (ANOVA) was used to determine differences between treatments using transformed data where necessary. Where required, repeat measures ANOVA was used. All results are reported at a significance level of p=0.05.

Results

Weather / soil moisture monitoring and irrigation scheduling - 2012

A summary of weather conditions during the growing season at the rain-shelter site (including comparison between inside and outside the rain-shelters) and open-field site are presented in Figure 8 and Figure 9. Not that there are some missing data at the open-field site during the season – this was largely a result of hare damage to the cables across the site, particularly in the early and mid-part of the season.

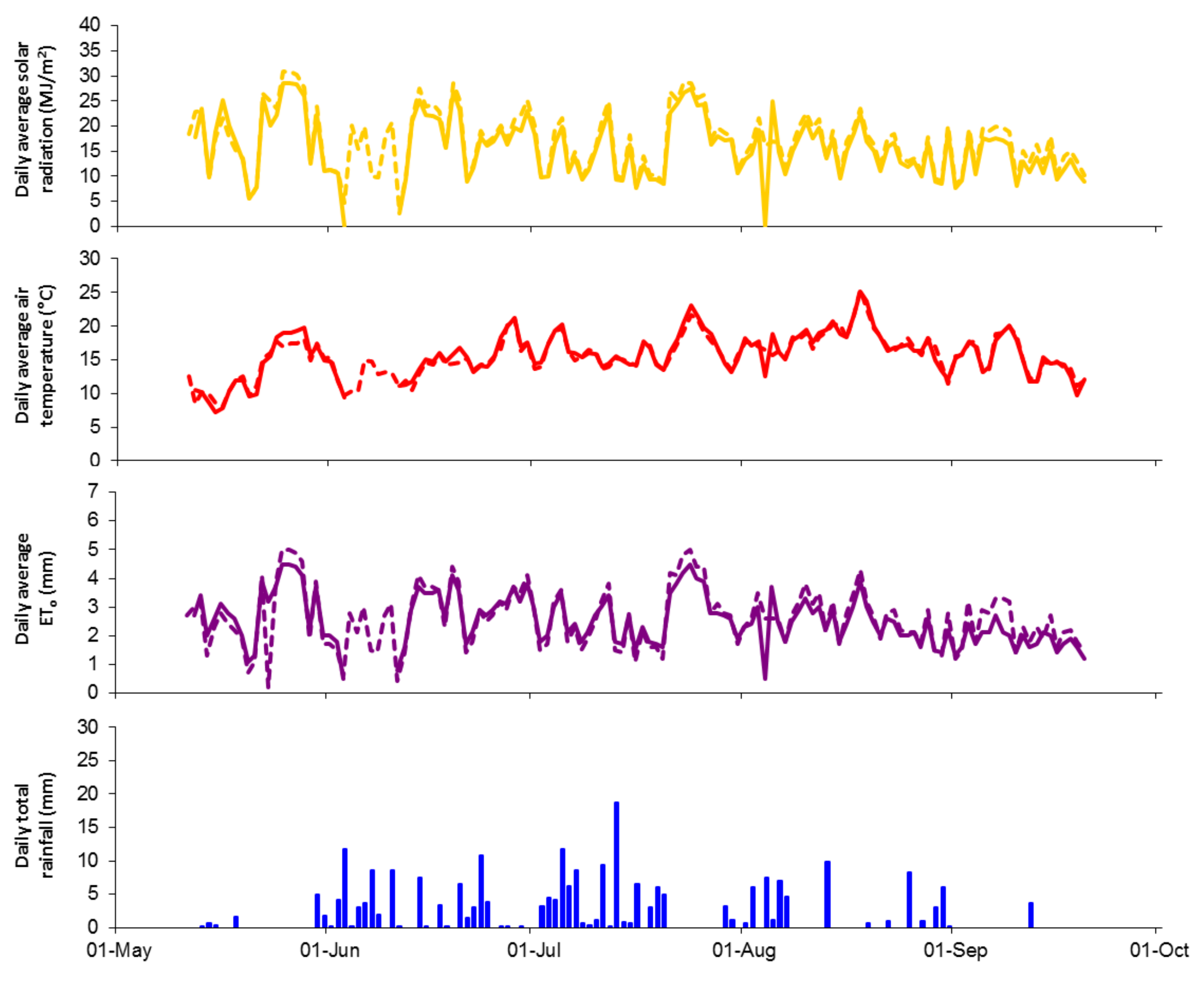

Figure 8 Weather at rain-shelter site during growing season. Solid line represents data within rain-shelter, dashed line outside rain-shelter. NB rainfall outside rain-shelter.

The 2012 season started with dry conditions continuing through the winter and early spring, prompting forecasts of severe drought in the summer ahead. However, from the beginning of April (shortly after drilling), wet conditions arrived and then persisted from April to mid-May and from the beginning of June until late August / early September. Much of the rain during this wet period fell as heavy showers. Although there were two periods of drier weather during the summer (late May for two weeks and most of September), the conditions severely limited the requirement to irrigate at the open-field site. The overcast conditions also resulted in cooler ambient temperatures and lower solar radiation inputs, which generally delayed crop maturity compared to typical years.

As with previous years, solar radiation and wind-speeds were lower within the rain-shelter at Broom's Barn than outside, but the average daily temperature was similar or often higher in the rain-shelter. Consequently, reference evapotranspiration (ET_0) within the rain-shelters was only slightly less (c3%) when compared to outside.

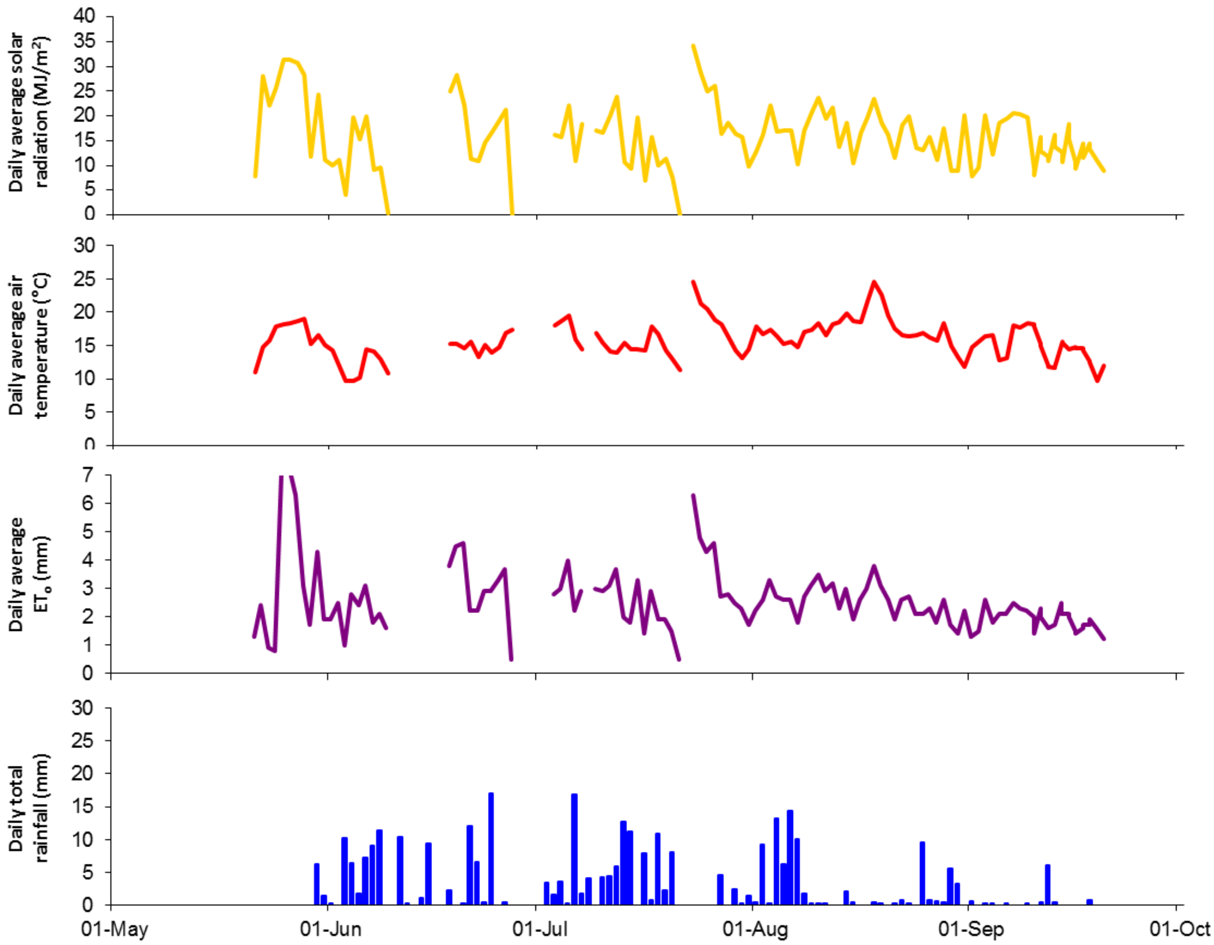

Figure 9 Weather at open-field site during growing season.

A summary of soil moisture deficit (SMD) in the root zone and irrigation applications through the season for each treatment is presented in Figure 10 (rain-shelter site) and Figure 11 (open-field site). Root zone was defined as the top 20cm of soil up until the point where significant quantities of water started to be removed from the 30cm profile, at which point the root zone was defined as the top 30cm for the remainder of the season.

Permanent wilting point at the rain-shelter site was assumed to be reached when soil moisture deficits reached 20%, 30% and 50% of AWC in the 0-10cm, 10-20cm and 20-30cm profiles as indicated by the non-irrigated control, H, during 2010 trials. On the slightly heavier soil at the open-field site, permanent wilting point was assumed to be reached when soil moisture deficits reached 20%, 25% and 35% of AWC in the 0-10cm, 10-20cm and 20-30cm profiles as indicated by the non-irrigated control, H, during 2010 trials. This gave an average available water content (AWC) of 39mm at the rain-shelter site and 45mm at the open-field site within the 30cm rooting zone. Irrigation applications were applied as per Table 3 based on the required quantity of water to bring the soil to the target level (either field capacity or approximately 50% of AWC, depending on regime) plus an additional approximately 2-4mm to account for evaporative losses from the soil surface.

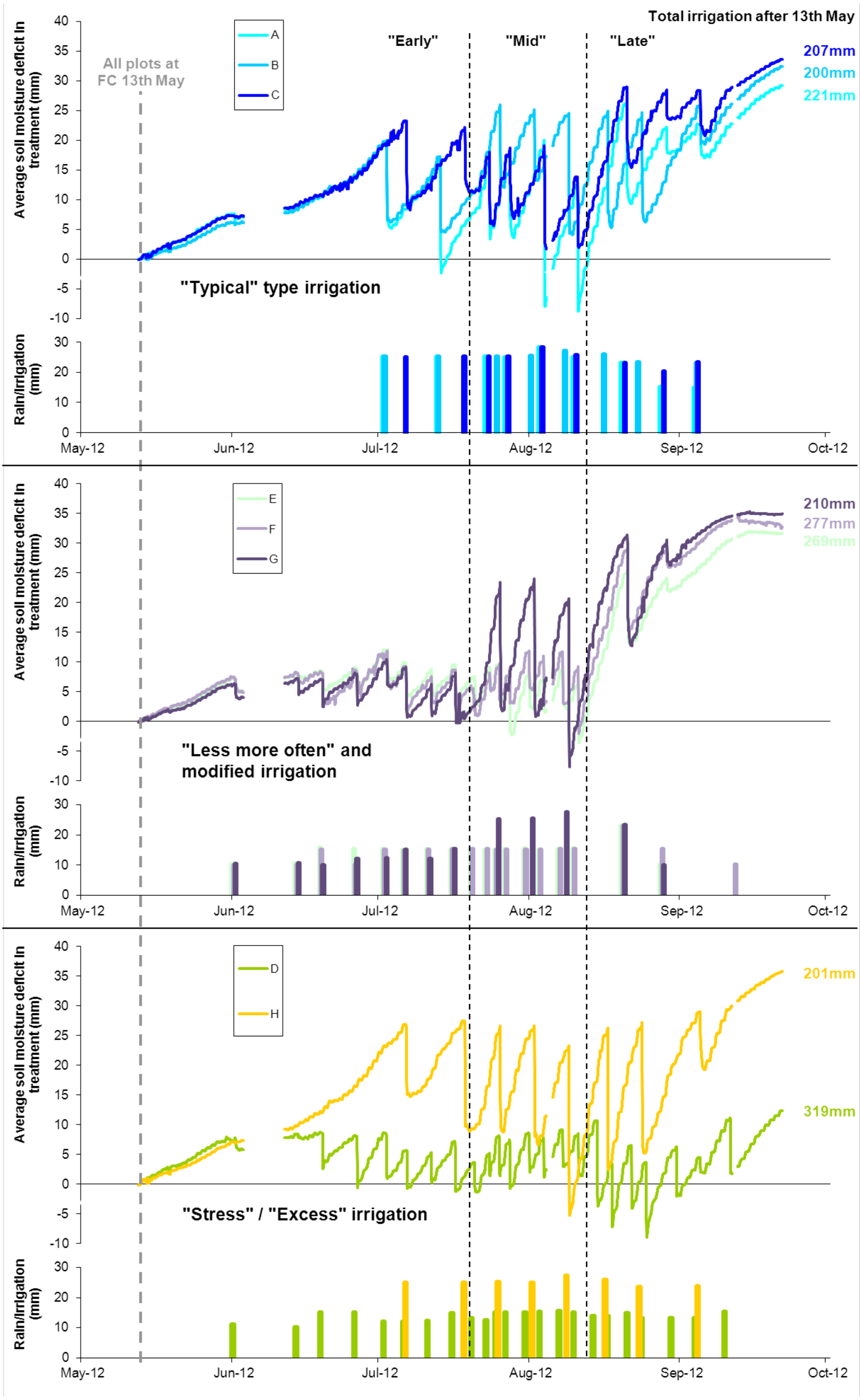

Figure 10. Soil moisture deficit in root zone and irrigation applications at rain-shelter site.

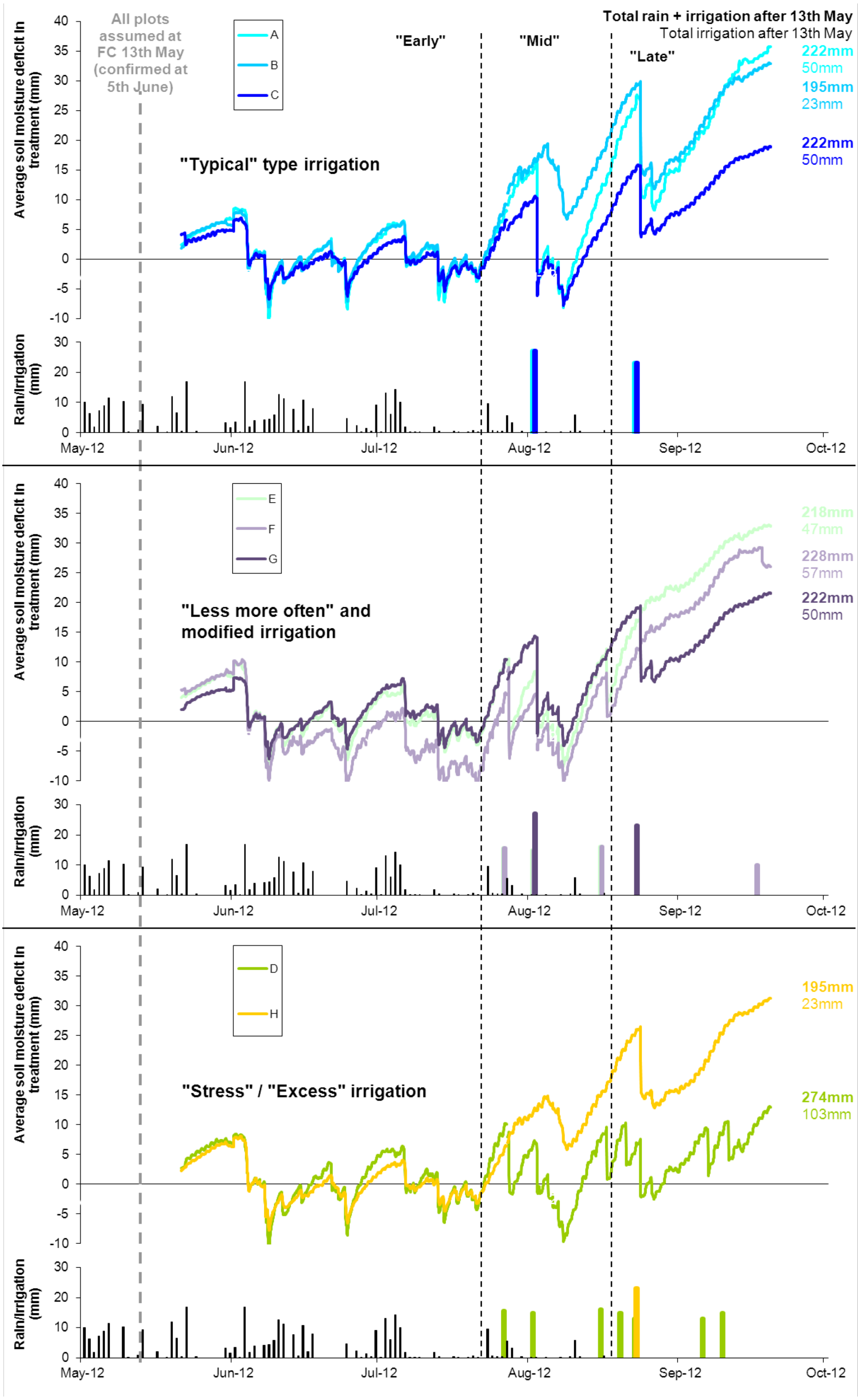

Figure 11 Soil moisture deficit in root zone and rain / irrigation at open-field site.

Table 4 summarises the number of irrigations and depth of irrigation applied to each treatment after initial wetting to field capacity (note FC achieved with rainfall in 2012, rather than irrigation in previous years). In general, irrigation regimes based on the “typical” field irrigation (A, B and C) were similar to field applications made by growers in 2012 – although little in the way of field applications was required as a result of the wet summer until some slightly drier spells in August and September. Typically around 25mm would be applied every 7-10 days during the main crop canopy building phase and the start of bulbing. During a typical season, growers would generally expect to apply between 100 and 150mm in 4-6 x 25mm applications.

Regimes based on a “less more often” principle (D, E, F and G) generally had around 12-15mm applied every 3-4 days and resulted in a greater total application than the “typical” type treatments. The exception to this was treatment G, which applied a total depth of irrigation similar to the typical regimes. The “stress” periods within both “typical” and “less more often” regimes generally had around 25mm applied every 10-14 days. Note that the “stress” regime in the rain-shelter trial had some misleading soil moisture readings due to a faulty probe, which led to some over-applications during the “mid” and the early part of the “late” part of the season.

It should be noted that the wet period from early April through to August significantly reduced irrigation requirements in the open-field trial site in 2012. As few irrigation applications were made during the season it is unlikely that water deficit stress was experienced in the open field site. In the 2012 season true water stress was probably only experienced in the rain shelter site.

Table 4. Summary of irrigation events applied to each treatment

Trt	Name	Rain-shelter			Open-field		
		Total number	Total depth	Average depth	Total number	Total depth	Average depth
A	**Typical, end season stress**	9	207mm	23.0mm	2	50mm	25.0mm
B	**Typical with mid+end season stress**	8	200mm	25.1mm	1	23mm	23.0mm
C	**Typical with early+end season stress**	9	221mm	24.6mm	2	50mm	25.0mm
D	**Less more often, no stress**	23	319mm	13.9mm	7	103mm	14.7mm
E	**Less more often, end season stress**	18	269mm	14.9mm	3	47mm	15.6mm
F	**Less more often, end season stress irrigation at 100% FO**	19	277mm	14.6mm	4	57mm	14.2mm
G	**Less more often early season, typical midseason, end season stress**	13	210mm	16.1mm	2	50mm	25.0mm
H	**Stress all season**	8	201mm	25.1mm	1	23mm	23.0mm

Crop performance - 2012

Note that wherever possible a convention has been adopted such that graphs of results from the rain-shelter site appear on the left, and the open-field site on the right. Note also that comments are largely limited to the rain-shelter site due to the lack of irrigation treatments that could be applied at the open-field site in 2012.

Crop establishment

Crop population at the time of harvest is presented in Figure 12. No significant differences in population were observed between treatments. Populations at the rain-shelter site were very close to the target of 52 plants/m^2. At the open-field site, populations were on average 20% lower than the target of 48 plants/m^2, largely due to poor conditions for crop establishment and some hare and rabbit damage.

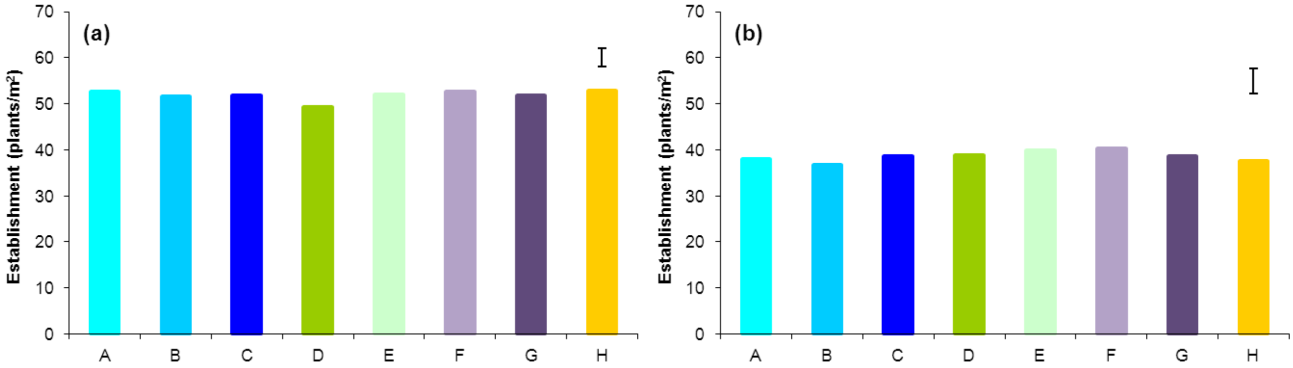

Figure 12 Crop population at harvest at rain-shelter site (a) and open-field site (b). Error bars show least significant difference (LSD).

Canopy growth

Canopy growth as percentage green cover measured by spectral ratio meter is presented in Figure 13. In general, crop growth followed typical patterns, with relatively slow development early in the season, followed by rapid canopy expansion before starting to mature and senesce. However the wet, cool conditions and low light levels of 2012 resulted in much slower crop development than previous years, particularly at the open-field site. Significant differences in canopy growth were observed between treatments in the rain-shelter trial at most measurements (except the early and late season). There were no significant differences in crop canopy cover at the open-field site.

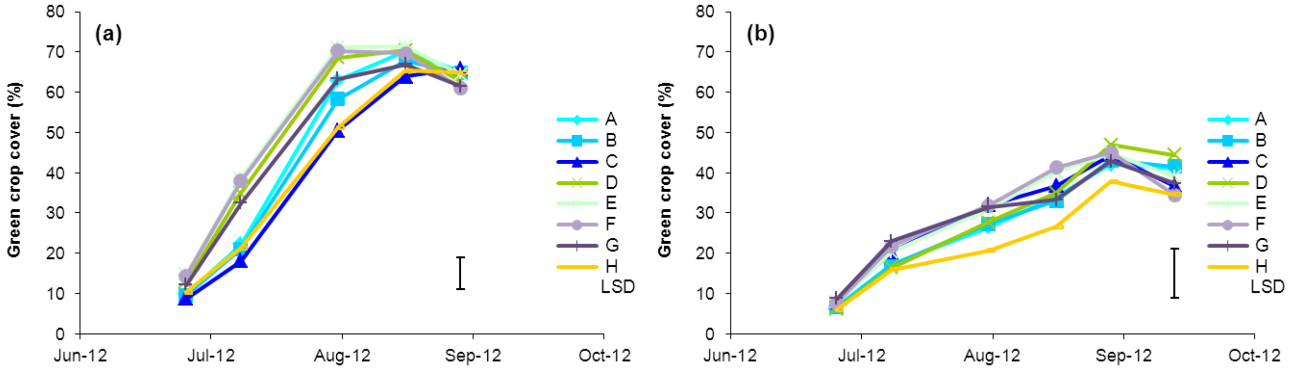

Figure 13 Crop canopy growth as % green cover at rain-shelter site (a) and open-field site (b). Error bars show LSD.

At the rain-shelter site, “less more often” treatments generated significantly greater canopy growth in the early part of the season when compared to equivalent “typical” irrigation regimes (D, E, F and G compared to A and B). Similarly, in mid-season, “little more often” regimes continued to promote greater canopy growth than “typical” regimes – though the difference between treatments was less marked (D, E and F compared to G). Regimes that stressed crop growth early in the season suffered from significantly slower canopy growth and achieved smaller canopies overall (compare C to A and B). Applying more water later in the season did not allow these crops to catch up with those without early season stress (e.g. C remained similar to H). Mid-season water stress also reduced canopy growth compared to “typical” applications, although the difference between treatments was less marked (B compared to A).

There were few consistent differences observed at the open-field site and none were statistically significant. However, “little more often” type regimes generally tended towards greater canopy cover and “stress” regimes tended towards the least cover

Vigour

Visual assessment of crop vigour is presented in Figure 14. Crop vigour follows a similar pattern to canopy cover, with significant differences between treatments being observed at the rain-shelter site particularly during mid-season but no significant differences being observed at the open-field site. “Less more often” treatments tended to result in more vigorous early crop growth and water stress in the early part of the season tended to significantly reduce crop vigour during the critical development phase. The stress treatment H showed significantly less vigour than most full irrigation regimes, particularly as the season progressed.

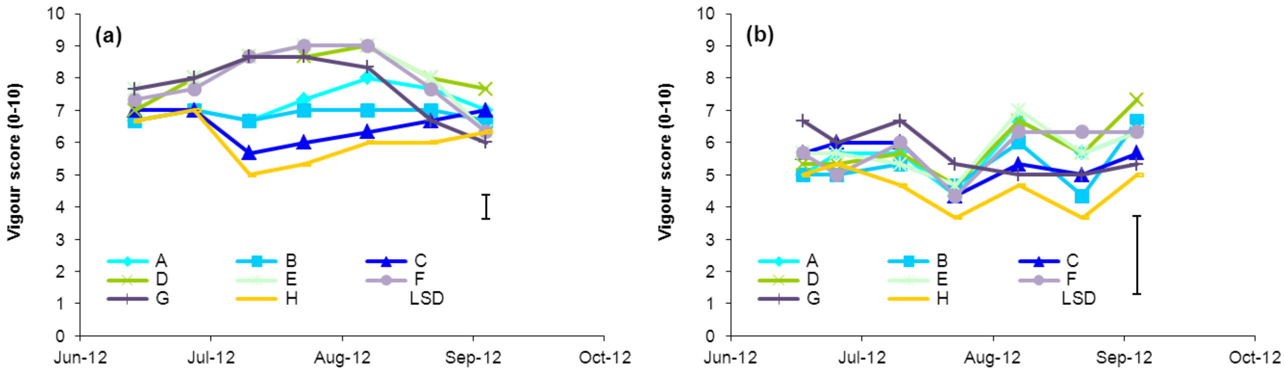

Figure 14 Crop vigour assessment at rain-shelter site (a) and open-field site (b). Error bars show LSD.

Biomass

Plant fresh biomass is presented in Figure 15. There were significant differences in plant biomass between treatments during the main canopy expansion phase at the rain-shelter site. At the open-field site, there were no significant differences between treatments. Plant biomass response to the irrigation regimes followed a similar pattern to crop canopy growth and vigour score. In general, “little-and-often” regimes promoted more rapid and greater biomass accumulation. Water stress, particularly in the early season, significantly slowed and reduced biomass accumulation (regimes C, G and H). Water late in the season when most regimes were following the typical “stress” pattern significantly increased fresh biomass approaching harvest (D compared to E and F).

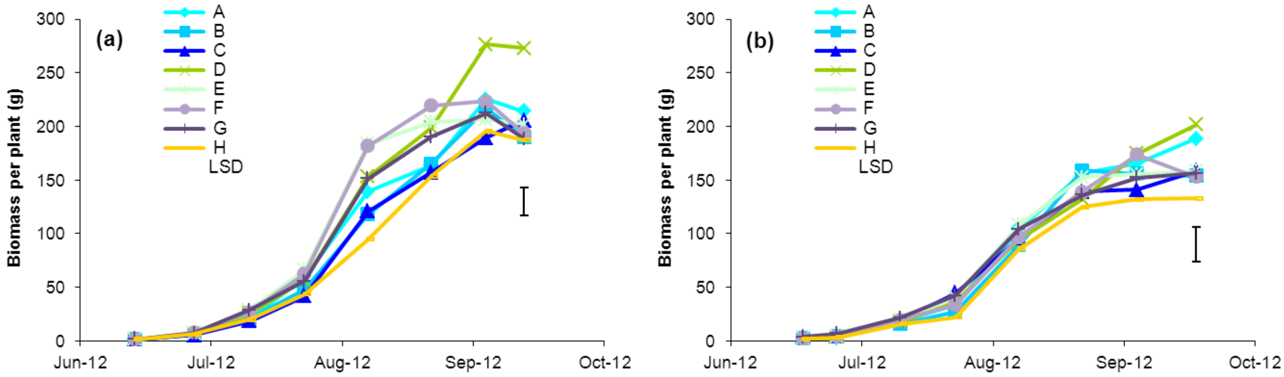

Figure 15 Crop biomass per plant at rain-shelter site (a) and open-field site (b). Error bars show LSD.

Fall-over and senescence

Crop fall-over progression and senescence are presented in Figure 16 and Figure 17. Crop fall-over was much earlier at the rain-shelter site than the open-field site. This was partly because the crop matured earlier under the rain-shelters, but also because the prolonged wet period during the summer (despite some drier weeks in late August and September) did not strongly initiate bulbing in the field. At the rain-shelter site, there were significant differences in fall-over during the period of rapid progression. Regimes with the largest canopies that experienced the typical end of season stress period had the most rapid fall-over progression (A, F and G). In contrast, treatments with smaller canopies due to early season (or continued) water stress (C and H) or those with large canopies and which did not experience the end of season stress period (D) exhibited much later fall-over. There were no significant differences in fall-over progression at the open-field site, however some broadly similar patterns to the rain-shelter site were observed.

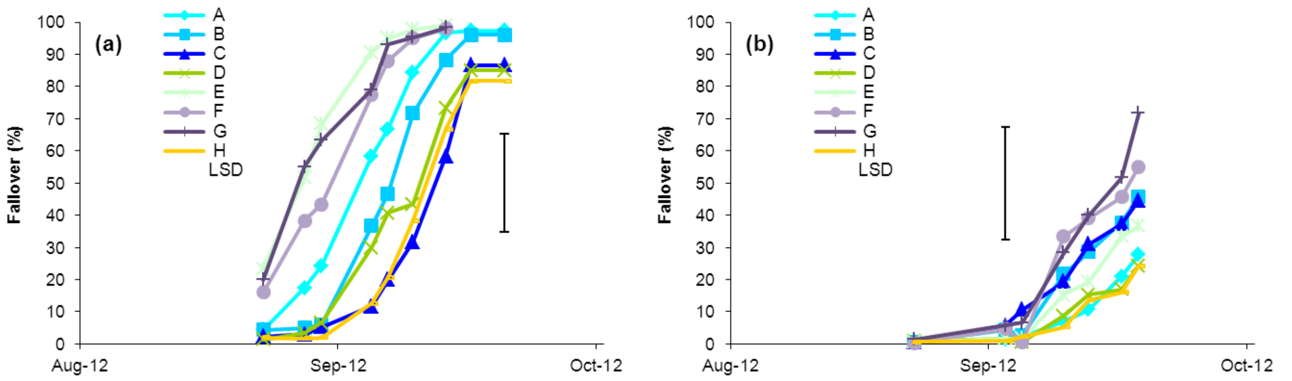

Figure 16 Crop fall-over progression at rain-shelter site (a) and open-field site (b). Error bars show LSD.

As with fall-over, crop senescence was considerably later at the open-field site than under the rain-shelter. Note that the open-field site was harvested with the majority of the crop showing a relatively low degree of senescence due to commercial harvesting requirements in the surrounding field. Under rain-shelters, senescence progressed significantly more rapidly in the crop with the quicker fall-over progression – e.g. treatments C,D and H fell over significantly later than most other treatments, and senesced significantly later as a result. At the open-field site, no significant differences in senescence were observed between treatments, but again some broadly similar patterns were noted.

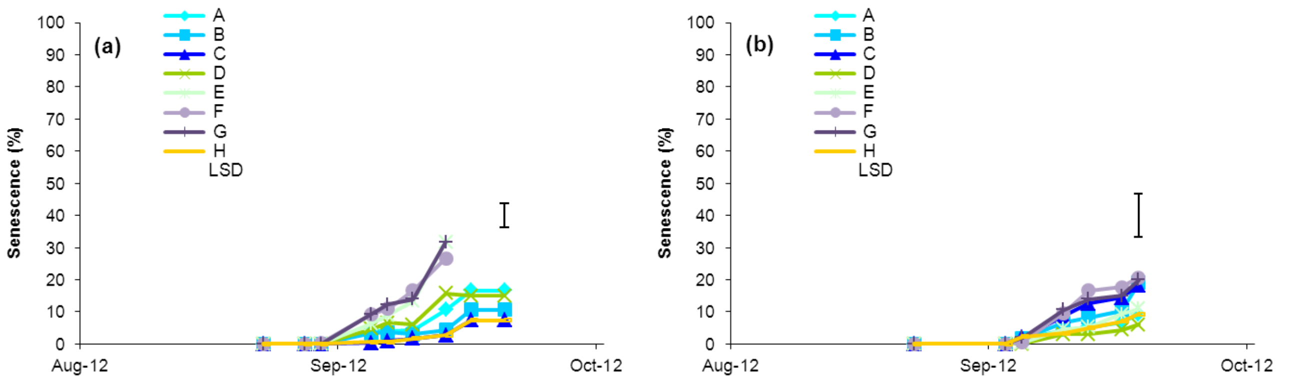

Figure 17 Crop senescence at rain-shelter site (a) and open-field site (b). Error bars show LSD.

Bolting

Crop % bolting is presented in Figure 18. There was no bolting observed at the open-field site. Although there were no significant differences in the level of bolting between treatments at the rain-shelter site, a slight trend towards more bolting in treatments which had greater early-season irrigation was noted (similar to 2011 results).

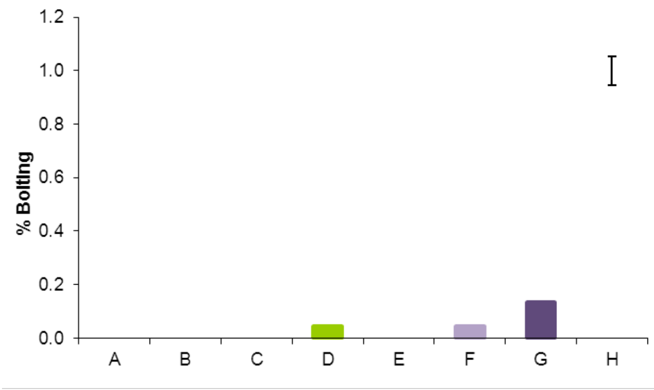

Figure 18 Crop % bolting prior to harvest at rain-shelter site. Note that there was no bolting at the open-field site, so data is not shown. Error bars show LSD.

Green yield

Green yield is presented in Figure 19. Yields at both sites were quite typical for a dry year (at the rain-shelter site) and a wet, cool and dull season with slow crop maturity (open-field site). Note that hand-harvesting tends to result in an estimated 10-15% greater yield than mechanical harvesting.

At the rain-shelter site, there were significant differences in green yield between treatments. Treatments without added water stress early or mid-season generally had significantly higher yields than those with additional water-stress periods. In particular, water stress early in the season (up to bulb initiation) significantly reduced green yields by 13% (C compared to A) whereas mid-season stress reduced green yields by 5% (B compared to A). Irrigating through to 50% fall-over produced a significant yield increase of 13% from a regime with end of season stress (D compared to E). Contrary to previous years, irrigating “little and often” produced significantly lower yields than the control “typical” regime – although this may relate to the timing of the last irrigation applications. Treatment G (with “little and often” early in the season, “typical” irrigation mid-season and the standard “stress” regime at the end) yielded very similarly to regimes that continued with “little and often” applications in mid-season (E and F) – but at a saving of approximately 60mm irrigation. The “stress” regime, H yielded 17% lower than the “typical” industry standard irrigation regime, A. There were no significant differences in green yield at the open-field site, although broadly similar patterns to previous years were noted.

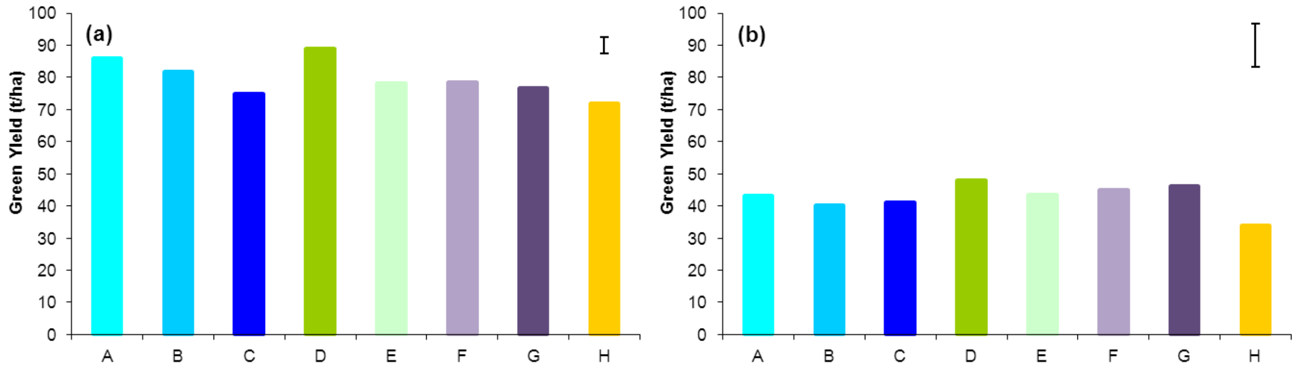

Figure 19 Crop green yield at rain-shelter site (a) and open-field site (b). Error bars show LSD.

Crop storability and quality

All samples are currently in storage under commercial onion cold-storage conditions, and will be assessed for quality and marketability in approximately April/May 2013.

Quality and storability biomarkers

Crop quality and storability biomarkers are currently being analysed at the laboratory: therefore no data can be presented here.

Crop storage – 2011

*Crop storability and quality – **2011** trial data*

This section presents post-storage data from the **2011** trial. Figure 20 presents post-storage size-graded yields.

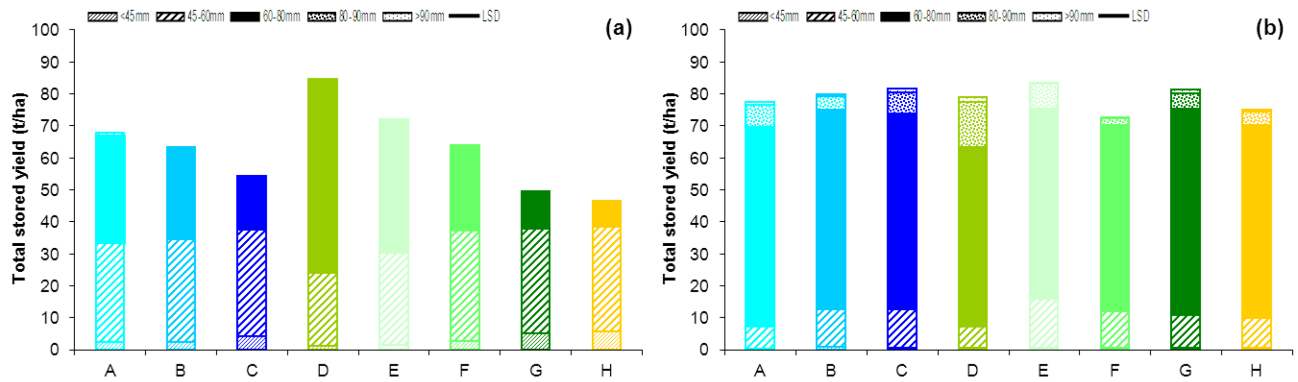

Figure 20 Crop post-storage size-graded yield at rain-shelter site (a) and open-field site (b).

Post-storage yields closely reflected green yields reported in the Year 2 annual report. There were significant differences in yields within most size grade categories at the rain-shelter site, but few differences at the open-field site. In general, irrigating “little more often” and irrigating closer to harvest tended to produce higher yields of larger sized bulbs and lower yields of smaller sized bulbs. Conversely, more restricted irrigation tended to limit larger sized bulbs and promoted smaller bulbs – particularly when the water stress period fell during the early part of the season.

Figure 21 presents post-storage crop dry matter content. Dry matter content was typical for onion crops, but did not differ significantly between irrigation treatments. However, there were some indications at the rain-shelter site that the "little more often" regime with later water (D) tended to reduce dry matter compared to more typical irrigation. In the final report, all data will be analysed to examine if later applications generally decrease dry matter.

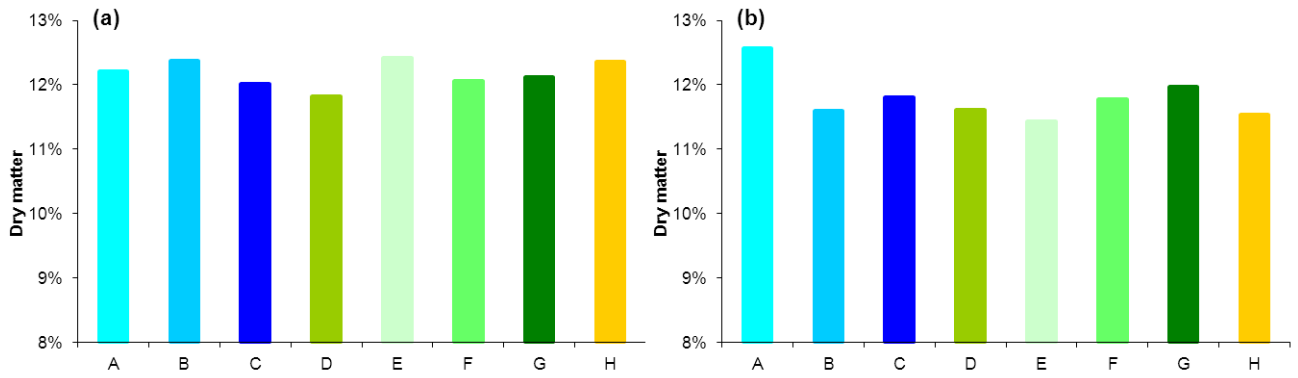

Figure 21 Crop dry matter content at rain-shelter site (a) and open-field site (b).

Figure 22 presents post-storage disease assessment data. At both sites, there were no significant differences in disease levels between irrigation treatments. Contrary to 2010 results, there were also no consistent trends in disease expression as a result of irrigation treatment.

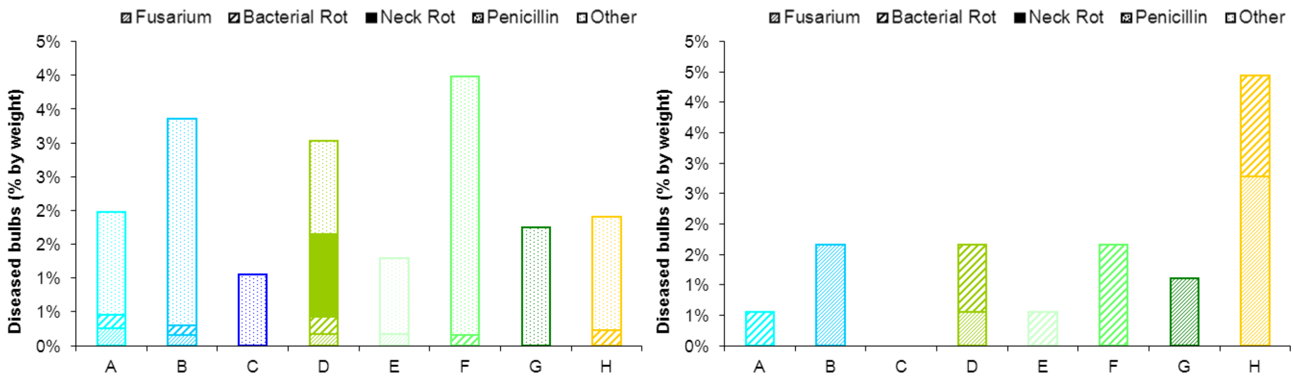

Figure 22 Crop post-storage disease at rain-shelter site (a) and open-field site (b).

As with 2010 data, there were no apparent relationships between irrigation treatment and the proportion of bulbs with double centres, internal die-back symptoms or in internal regrowth levels, skin finish or shape (except the non-irrigated treatments which tended to have a more elongated shape). Consequently, this data is not displayed here.

*Quality and storability biomarkers – **2011** trial data*

Crop quality and storability biomarker data have been analysed, however, it is suggested that they are best presented in the final report rather than in this annual report.

Crop pest and disease - 2012

The results for thrips (*Thrips tabaci*) observations in 2012 are presented in Figure 23. Thrip levels were much lower than in previous years, largely due to the on-going wet conditions. Consequently, there were no significant differences in thrip damage at the rain-shelter site, and no damage was noted at the open-field site.

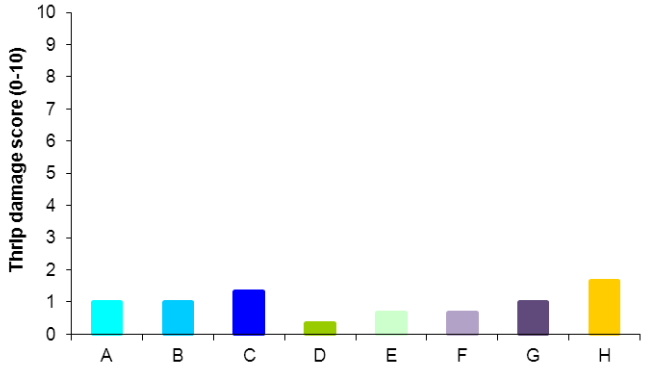

Figure 23 Thrip severity score at rain-shelter site. Note that no thrip damage was observed at the open-field site, so data is not displayed.

The results for downy mildew (*Peronospora destructor*) incidence and severity are presented in Figure 24. At both sites, relatively little downy mildew was observed, largely due to the dry conditions experienced under protection in the rain-shelter and the efficacy of commercial fungicide programmes at the open-field site. However, at the rain-shelter site, a little downy mildew was noted in some plots, but did not develop aggressively under the low humidity conditions. The greatest downy mildew expression tended to be observed on the treatments with “little and often” irrigation, particularly where this was continued until the end of the season (D).

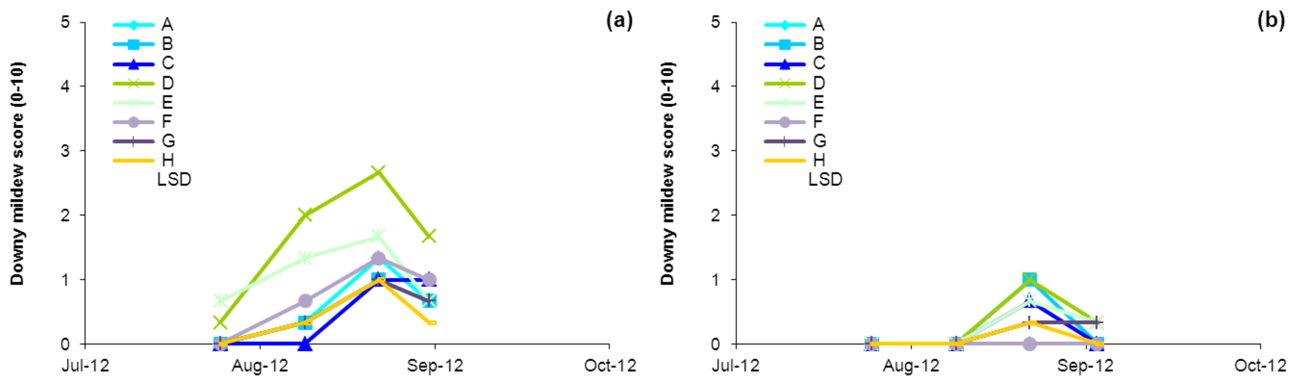

Figure 24 Downy mildew incidence and severity score at rain-shelter site (a) and open-field site (b).

Results for leaf blight (*Botrytis squamosa*), leaf blotch (*Cladosporium allii* / *C. allii-cepae*), secondary bacterial infection and bacterial rots are not presented here. All were present at relatively low levels from late July onwards, generally being greater at the open-field site. Disease levels generally increased slightly through to harvest at the rain-shelter site, but decreased at the open-field site since the crop there continued to grow fresh foliage rather than mature and start to senesce. In most cases, levels of these diseases were marginally higher in irrigation treatments that had more frequent irrigations and which continued later in the season, however this was not conclusive.

Soil nitrate leaching - 2012

Soil ammonium N and soil nitrate N in the 0-30cm and 30-60cm profiles are presented in Figure 25 to Figure 28. Characteristic of soil nutrient measurements, data from both sites were very variable, with typically a two-fold variation seen between replicates, but up to 10-fold in some cases.

Although the variability in observed data resulted in few statistically significant differences between treatments in ammonium or nitrate levels within the 0-30cm or 30-60cm profile at either site, there were some apparent trends. Irrigation regimes with the greatest quantity and frequency of water (especially early to mid-season) generally tended to have lower levels of ammonium and nitrate N in the 0-30cm and 30-60cm profiles than regimes with less water. This may suggest that some leaching may have occurred, but may also reflect the greater crop growth observed in the “wetter” treatments than in more stressed regimes.

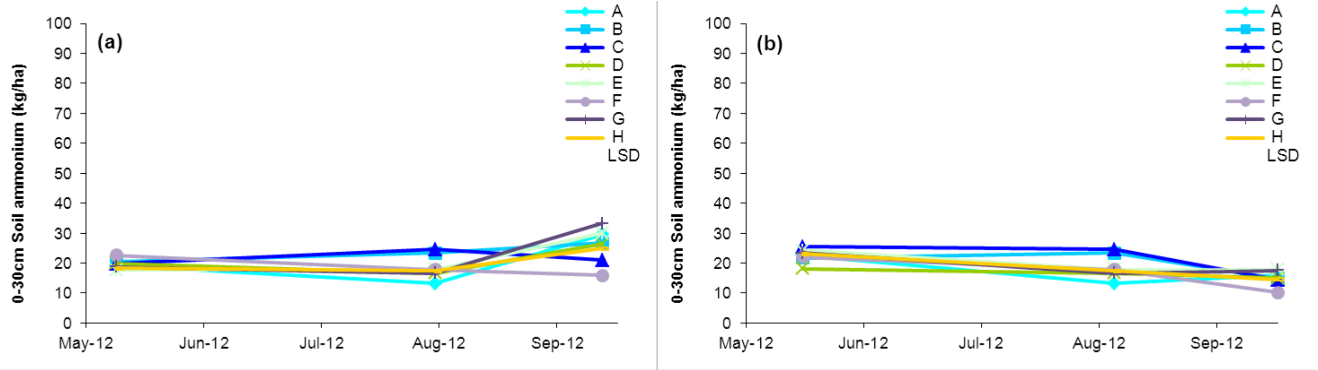

Figure 25. Soil ammonium N in 0-30cm profile at rain-shelter site (a) and open-field site (b).

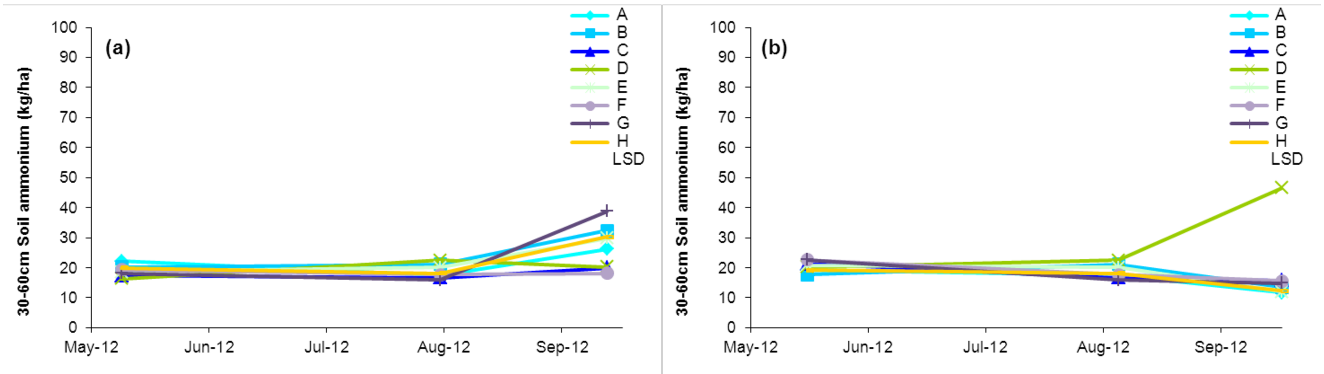

Figure 26. Soil ammonium N in 30-60cm profile at rain-shelter site (a) and open-field site (b).

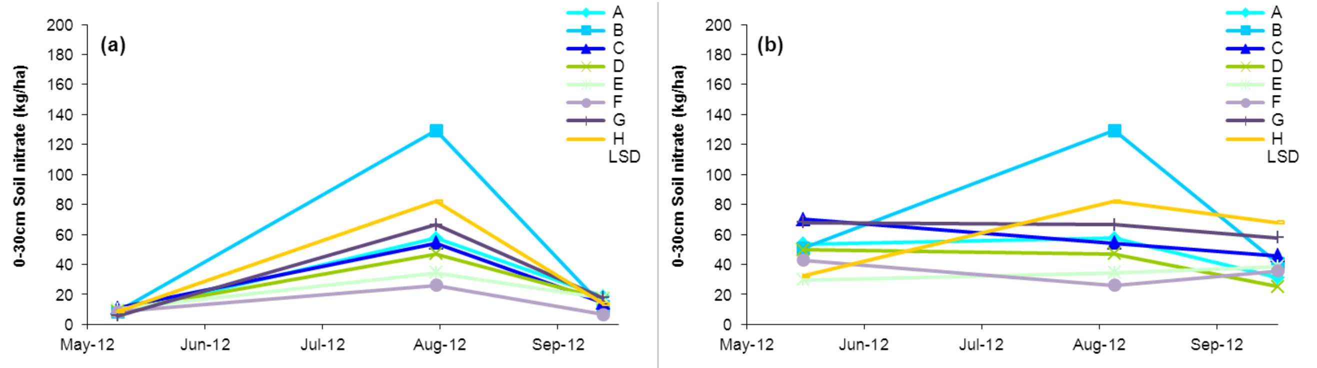

Figure 27. Soil nitrate N in 0-30cm profile at rain-shelter site (a) and open-field site (b).

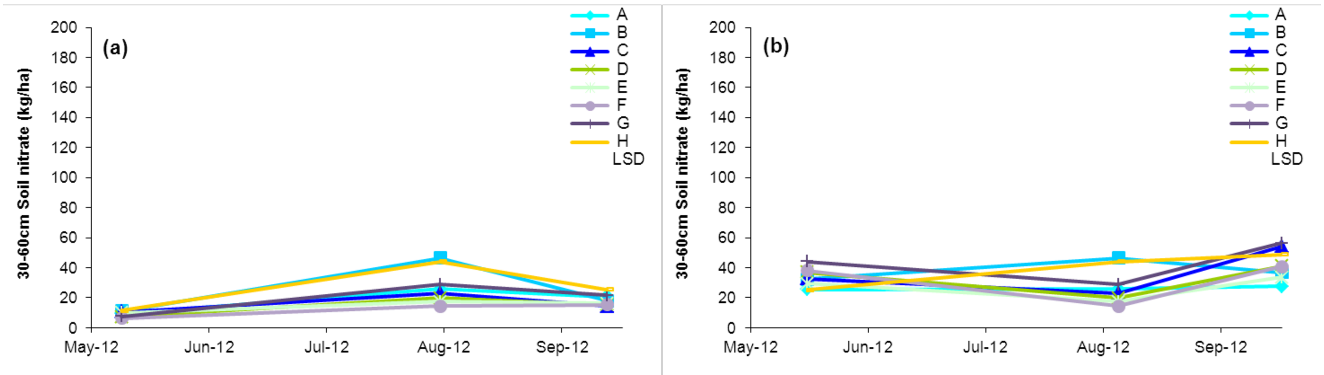

Figure 28 Soil nitrate N in 30-60cm profile at rain-shelter site (a) and open-field site (b).

Weed response - 2012

Weed scores at harvest are presented in Figure 29. In the rain-shelter, there were relatively clear differences in weed pressure as a result of the irrigation regime applied. The majority of weeds in the rain-shelters were fat hen, nightshade, pansy, speedwell, chickweed, groundsel and sow thistle. Regimes with frequent applications (particularly late-season) tended to have a higher weed pressure than those which received less frequent irrigation. The lowest weed pressure tended to be observed in treatments with water stress in early and mid-season. Observations at the open-field site were somewhat variable (largely due to effective herbicide programmes and some weed patches) and it is therefore likely that little can be interpreted from weed results on this site.

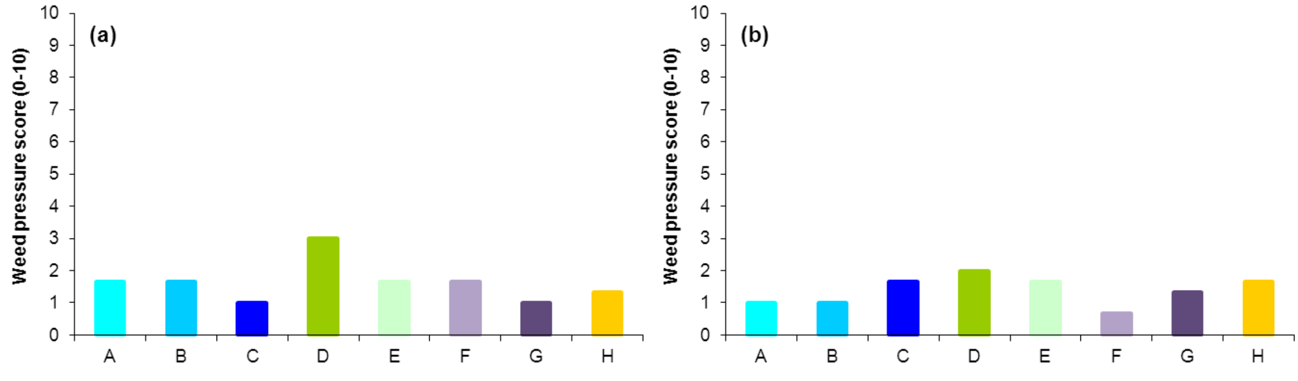

Figure 29 Weed score at harvest at rain-shelter site (a) and open-field site (b).

Irrigation efficiency, cost-benefit and identifying optimal irrigation regimes – 2012

Although the evaluations of irrigation efficiency, cost-benefit and optimal irrigation regimes are best reserved until sufficient data has been accumulated later in the project, some preliminary results are presented in Figure 30, also including 2010 and 2011 data. These data indicate a strong and direct correlation between total water received by the crop and green yield at water inputs of <300mm. At levels of water input greater than this, the relationship starts to degrade and appears to become somewhat negative. It is suggested that some of the relationship breakdown at high water input levels may relate to reduced crop growth as a result of the lower light levels which correspond with increased rainfall input. Indications from the data to date are that onion crop yield increases by between 0.25 and 0.3 t/ha for every mm of irrigation and/or rainfall received by the crop up to around 300mm total, where the response appears to plateau or decrease. Further refinement of this relationship is planned for the final report – including removing water received prior to crop emergence and removing the proportion of water at each rainfall/irrigation event that is estimated to be lost as evaporation from the soil surface.

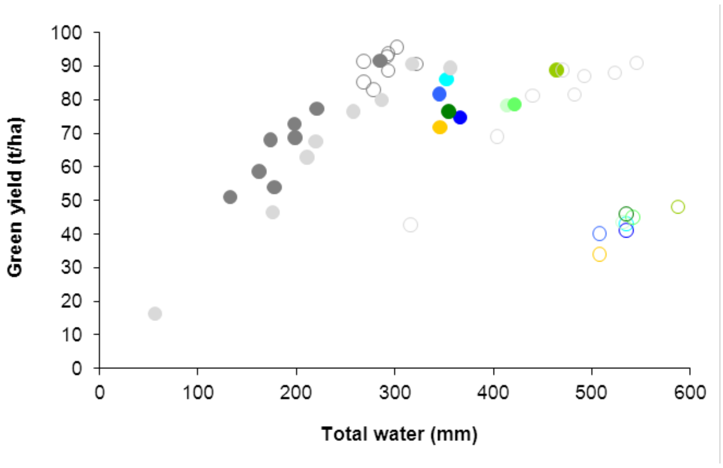

Figure 30. Relationship between total water received by crop from drilling to harvest and green yield at the rain-shelter site and open-field site during 2010, 2011 and 2012. Closed circles represent the rain-shelter site and open circles the open-field site (coloured = 2012, dark grey = 2011 and light grey = 2010)

Discussion

Firstly, it should be noted that, similar to 2011, the open-field site received an unusually large number of rainfall events (mostly small, but some heavier showers) during the majority of the growing season from early April until harvest (with occasional periods of drier weather in late May and September). Consequently, few irrigation treatments could be applied to this site and, as a result, there are few significant differences in crop performance, pests, disease and weeds in the data from this site. However, the data from the rain-shelters once again provided some very useful information despite the "stress" regime receiving a little more water than intended due to faulty soil moisture readings. The majority of the discussion will therefore focus on the rain-shelter site unless specified.

Irrigation regime did not affect crop establishment or survival at either site in this trial, given the fact that crops needed to be established before differential irrigation regimes could commence.

As with 2010 and 2011, the irrigation regime applied to plots had a profound effect on crop growth (whether measured as % green crop cover, visual assessment of crop vigour or plant biomass). Irrigation regimes that applied less water more often tended to drive crop canopy cover development and increased crop vigour and biomass over more typical regimes of c25mm every 7-10 days. In particular, it was apparent that irrigation regimes which induced water stress in the crop early in the season (prior to bulb initiation) significantly reduced both the rate of crop development and the total canopy or biomass achieved. Although the more “typical” irrigation regimes tended to ultimately achieve similar canopies to “less more often” regimes by the end of the season, those with water stress during the mid or particularly early season did not manage to recover.

In turn, any increased canopy development translated almost directly into increased crop green yield, following relatively well understood principles of resource partitioning to storage tissues. There were also clear signs from the rain-shelter site that not deliberately inducing water stress late in the season (only up to 50% fall-over in this trial) increased green yields over the typical practice. Unlike previous years, the “less more often” treatments yielded less than the equivalent “typical” regime. This may have resulted from the timing of the last irrigation on the treatments which could have supported more late-season growth in the “typical” regimes.

No significant differences in the proportion of plants bolting (prematurely flowering) were noted at the rain-shelter or open-fields sites. There was, however, a general trend to support the observations of 2011 that those treatments which promoted increased early canopy growth (i.e. “less more often” regimes) tended to have a greater proportion of bolting plants than more typical regimes. This increased bolting may relate to the crop being more advanced than usual around the time that the appropriate day-length trigger causes the switch of resources from leaf to bulb production. Consequently, the plants may react as though they are in the second year of their biennial cycle and therefore produce flowers. It is worth noting that, although the percentage of bolting plants was relatively low, bolting at levels of only 0.5-1% in a field situation is enough to cause concern to growers.

Currently all 2012 harvest samples are in storage under typical commercial conditions and will be assessed for crop quality and marketability in April/May. Analysis of 2011 samples indicated that irrigation regimes which applied the greatest amount or frequency of irrigation through the season (particularly early season, but also close to harvest) tended to promote larger bulbs and fewer small bulbs. As with 2010 storage samples, there did not appear to be any significant increase in storage diseases as a result of irrigation regimes that applied more water, more frequent water or later water – contrary to commercial experience.

There were indications that more frequent irrigation reduced thrip damage under the rain-shelter. These results reflect accepted knowledge that overhead irrigation is an effective control agent for onion thrips.

Disease levels were generally quite low at both sites, although there was a trend towards greater downy mildew expression in treatments with more frequent water applications during the mid and late parts of the season.

Soil ammonium N and nitrate N levels were characteristically variable and there were few significant differences between the irrigated regimes. However, there were some indications that regimes with less water may have retained a greater proportion of soil ammonium and nitrate than those that applied more water and/or with more frequent irrigations. This may suggest some leaching through the profile, or it may reflect the greater crop growth in these plots.

Weed pressure appeared to be generally higher under those irrigation regimes that applied water more frequently and in the early to mid-season.

This project had 4 objectives:

1. To investigate and evaluate the impacts of a range of irrigation practices on the following characteristics of Rijnsburger bulb onions:
    a. Crop growth and development (establishment, vigour, biomass accumulation and maturity)
    b. Yield
    c. Bulb quality (e.g. size, skin finish, morphology, diseases such as Fusarium, bacterial rots etc.)
    d. Storability
2. To evaluate the implications of these practices on:
    a. Foliar pests and diseases (particularly thrips and downy mildew)
    b. Justifying irrigation usage and demonstrating efficient water use

   c. Nitrate leaching
   d. Weed flushes
3. To identify optimal irrigation practices for bulb onions based on these evaluations.
4. To produce “best-practice” guidelines for UK growers on the irrigation of bulb onions for storage

The data discussed here address objectives 1 and 2 of the project, although further data has yet to be gathered from the 2012 season trials (primarily storage data). Objectives 3 and 4 are long-term goals of the project, and will require data from all 3 years trials.

Conclusions

The 2012 season trials have continued to provide very useful data to project FV 326a. Eight irrigation regimes were investigated for their impact on onion crops both under rain-shelters and in a commercial open-field site. Significant differences were observed between irrigation treatments under the rain-shelter. Differences between treatments were not significant at the open-field site, largely due to the abnormally wet period from early April until harvest.

In general, as found in 2010 and 2011, onions respond well to water, with more frequent applications of smaller amounts tending to drive canopy development and crop vigour more than typical applications of c25mm every 7-10 days. The most critical period for driving this canopy growth appears to be early in the season (prior to bulb initiation). This increased canopy development largely translates into greater yield. However, late application of water also tends to increase yields, most likely due to direct water uptake by the bulb.

Analysis of 2011 storage data showed little significant effects of irrigation regime on storability of onion bulbs (contrary to field experience), but backed up previous yield data with size-grading information. 2012 crop samples are currently in cold-storage for analysis in April/May 2013.

Until all the results are analysed together for the final report, the authors are reluctant to advise significant changes to irrigation practices based on the data generated to date. However, it is becoming relatively clear that it may be wise for growers to consider prioritising irrigating their onions in the early season to promote canopy at least up to the point of bulb initiation – bearing in mind the potential for increased bolting in excessively forward crops.

Knowledge and Technology Transfer

A short review article was published in the HDC Field Vegetable Review magazine in spring 2012, providing an update on trial progress. A short article was also featured in the Vegetable Consultancy Services Root Vegetable Grower newsletter (March) which is circulated to growers covering approximately 50% of the UK onion area. In addition, results were presented internally to a number of large onion growing clients. Although it was intended to coincide a field day with the annual open day at Broom's Barn Research Centre during June 2012, this could not be arranged.

Data from the irrigation trial has been shared with the LINK project HL0196 "Developing precision irrigation for field-scale vegetable production, linking in-field moisture sensing, wireless networks and variable rate application technology". This data will assist the project to validate onion growth and water response models. Meetings with the project co-ordinators are planned for 2013 to share further data between the LINK project and FV 326a.