Project title: Minimising post-harvest losses in radish through an understanding of pre and post-harvest factors that influence root splitting.

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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 with detail and 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.
GROWER SUMMARY

Headline

Irrigation frequency and timing both tend to affect pre-harvest splitting whereas irrigating to different soil moistures tends to affect splitting which occurs post-harvest.

Background and expected deliverables

Splitting of the tap root and hypocotyl in radish (Raphanus sativus) results in losses of up to 30% after arrival at the pack house and is a fundamental problem for growers. Despite both economic and technical requirement for knowledge in this area the causes of root splitting in radish have yet to be fully explained and there is a lack of information and scientific investigation in this area.

Root splitting in radish is normally characterized by splits along the length of the radish which occurs pre-harvest or shortly (1-2 days) post-harvest during storage. It is a major problem for growers as incidence of splitting can be as great as 30% on arrival at the packhouse. These levels easily exceed supermarket tolerances; which typically require less than 10% splits, and results in batches having to be reworked which is costly. Despite these problems, little is known about the environmental and physiological causes of splitting.

European radish has a rapid growth cycle; characteristically 4 weeks from planting to harvest, with high growth rates. Therefore the correct use of irrigation and an adequate water supply is thought to be fundamental to successful radish growth. Irrigation is used to maintain soil water potential ($\Psi_m$) by replacing moisture lost through evapotranspiration. Optimal levels of soil moisture will provide the plant with enough water to sustain its physiological needs. However, both inadequate and excessive amounts of water are stressful to the plant. There is a paucity of information regarding splitting in relation to $\Psi_m$ in radish but research into splitting in other swollen hypocotyls, root crops and tubers suggests irrigation may be an important factor in splitting.

The aims of the project this year were to define the effect of pre-harvest soil water status on root splitting. The specific objectives were to:

1. Determine if the size of fluctuations in soil moisture content affects splitting pre and post-harvest
2. Determine if irrigating to different soil moisture contents affects splitting pre and post-harvest
3. Determine the effects of different irrigation regimes early and late in radish growth on splitting pre and post-harvest
Summary

In 2011/2012 experiments were carried out to investigate the effects of irrigation and soil moisture content on the incidence of splitting in radish.

Objective 1

Initial experiments found a non-significant trend linking soil moisture content and splitting. There was a greater incidence of split radish occurring at harvest in the treatment groups with greater fluctuations in soil moisture content. The treatment group which was watered the most frequently and therefore experienced the smallest fluctuation in soil moisture has the least number of splits whereas the group which had the largest fluctuation in soil moisture has the largest number of splits.

Objective 2

No difference was observed in the rates of splitting at harvest of plants irrigated at the same frequency to different soil moisture contents. However, post-harvest a non-significant trend was observed with plants which were irrigated to a greater soil moisture content splitting more during storage. Irrigating at the same frequency to different soil moisture contents was also found to have an effect on the speed to growth of the radish plants; plants which were irrigated to greater soil moisture contents grew more rapidly and were ready for harvest sooner than radish plants watered to lower soil moisture contents.

Objective 3

To investigate this objective during the four week growing period of radish plants were given different irrigation treatments for the first and last two weeks of growth. The first group was watered to field capacity for the duration of the experiment. Field capacity is the maximum amount of water that a soil can hold over the force of gravity. The second group was watered to field capacity for the first half of the experiment then given deficit irrigation for the second half of the experiment. The third group was given deficit irrigation for the first half of the experiment then watered to field capacity for the second half of the experiment and the final group was given deficit irrigation for both halves of the experiment. Under deficit irrigation plants were irrigated with 25% of the water lost due to evapotranspiration since the last irrigation.

Irrigation timing was found to have a non-significant effect on splitting but there was a trend. The group which received deficit irrigation for the first two weeks and then irrigation to field capacity for the final two weeks tended to have less splitting on average per pot than the other treatments; other treatments were all similar in their rates of splitting on average per
pot. The yield for this group was similar to that of the group which received irrigation to field capacity for the duration of the experiment and significantly greater than the groups which received deficit irrigation for the duration or the group which received irrigation to field capacity followed by deficit irrigation. This would suggest deficit irrigation during initial growth is adequate for development at this stage and watering to field capacity at this point is actually detrimental in terms of splitting at harvest, it would also suggest deficit irrigation during the final two weeks of growth increases splitting at harvest. These results also indicate irrigation during the final period of growth determines yield.

Financial benefits

UK radish producers encounter frequent problems with post-harvest splitting in radish which has a significant commercial impact in terms of product wastage. Identification and removal of splits is both time consuming and wasteful and is not always successful which results in depot rejection and further cost. The direct impact on the consumer is not known, but is thought that the split roots and drying/deterioration of the split surfaces may also deter sales.

Action points for growers

- Do not over water plants during early growth. Water requirement at this stage is less than later in development and excessive water tends to increase the number of splits at harvest
- Ensure plants have adequate water in later growth. Irrigation in the final two weeks has been shown to affect yield. Watering to greater soil moisture content increases the yield
- Watering plants to consistently high soil moisture contents tends to increase the incidence of splitting during storage and should be avoided
- Do not expose plants to large fluctuations in soil moisture content. Large fluctuations in soil moisture content tend to result in more splitting
SCIENCE SECTION

Introduction

Splitting of the tap root and hypocotyl in radish (Raphanus sativus) results in losses of up to 30% after arrival at the pack house and is a fundamental problem for growers. Despite both economic and technical requirement for knowledge in this area the causes of root splitting in radish have yet to be fully explained and there is a lack of information and scientific investigation in this area.

Physiologically radish (Raphanus sativus), like celeriac, beetroot and turnip is a swollen hypocotyl. It is an economically important member of the mustard family Cruciferae (Brassicaceae). European radish has a rapid growth cycle; characteristically 4 weeks from planting to harvest, with high growth rates. Therefore the correct use of irrigation and an adequate water supply is thought to be fundamental to successful radish growth.

Root splitting in radish is normally characterized by a radial longitudinal fracture which occurs pre-harvest or shortly (1-2 days) post-harvest during storage. It is a major problem for growers as levels of splits can be as high as 30% on arrival at the packhouse. These levels easily exceed supermarket tolerances; which typically require less than 10% splits, and results in batches having to be reworked which is costly. Despite these problems, little is known about the environmental and physiological causes of splitting.

Irrigation is used to maintain soil water potential (Ψm) by replacing moisture lost through evapotranspiration. Optimal levels of soil moisture will provide the plant with enough water to sustain its physiological needs. However, both inadequate and excessive amounts of water are stressful to the plant. There is a paucity of information regarding splitting in relation to Ψm in radish but research into splitting in other swollen hypocotyls, root crops and tubers suggests irrigation may be an important factor in splitting. Kang and Wan (2005) carried out investigations into the effect of Ψm on a larger type of radish which takes longer to reach maturity than is typically grown in the UK; Raphanus sativus L. cv. ‘Dahongpao’ and ‘Mantanghong’. This investigation found radishes irrigated to their mid-treatment Ψm of −0.035 MPa in the field had the lowest cracking rate and radishes irrigated to Ψm of −0.015 MPa had the highest cracking rate. However, further research is required as yield results in that investigation differed in year one and two. Additional investigation is also required to establish how and why the splitting occurs, to investigate a broader range of Ψm and to investigate the effects of soil water potential on European radish.

The experiments carried out between October 2011 and October 2012 were as follows:
Experiment 1: Investigating the effects of irrigation frequency on the prevalence of cracking in European radish (*Raphanus sativus* cv. Rudi).

Experiment 2: Investigating the effects of water potential on cracking in European radish (*Raphanus sativus* cv. Rudi).

Experiment 3: Investigating the effects of irrigation timing on cracking in European radish (*Raphanus sativus* cv. Rudi).

Experiment 4: Investigating the different cracking susceptibility of different radish (*Raphanus sativus*) cultivars.

All experiments were conducted in glasshouse number 5 in the Crops and Environment Research Centre at Harper Adams University College. Glasshouse conditions were: 16 hour day, 15/5°C day/night temperature. Relative humidity and temperature were logged in the glasshouse using TGP 4500 TinyTag logger (Gemini Data Loggers (UK) Ltd., Chichester, UK). Storage was carried out in Sanyo Versatile Environmental Test Chamber Model: MLR-351H (Sanyo Electric Co., Ltd., Japan) in the Princess Margaret Laboratories at Harper Adams University College. As above, Relative humidity and temperature were logged in the growth cabinet using a TGP 4500 TinyTag logger. The growth cabinet was set to 3°C as this is within the range used commercially to store radish; typically commercial radish are stored between 2 and 5°C. The radishes were stored with no light and 90% relative humidity to prevent desiccation.

**Statistical analysis**

All data was analysed using GenStat for Windows 15th Edition (Payne 2012). If data was parametric as confirmed by Shapiro-Wilk test for normal distribution it was analysed using dose-response ANOVA. Where data was not normally distributed and could not be transformed the non-parametric Friedman’s test was used.

**Experiment 1: Investigating the effects of irrigation frequency on the prevalence of cracking in European radish (*Raphanus sativus* cv. Rudi).**

**Materials and methods**

Radish were grown in 4.2 L pots containing a 1:1 mix of horticultural sand and John Innes No. 2 growing medium (Keith Singletons Horticultural products, Cumbria, UK). Preliminary experiments showed a 1:1 mix of compost and sand had a greater difference between weight at saturation and weight at field capacity (the term ‘field capacity’ in this report is used to describe pot capacity) compared to compost alone and the mix reached a steady weight quicker than compost alone. This suggests compost has greater water retention than a mix
of compost and sand, hence using a mix would give a greater difference in experimental treatments as the water will be more freely available to the plant roots and result in more rapid water loss from the growing medium.

Pots were uniformly filled and watered to the weight at field capacity. The weight at field capacity had previously been calculated by filling 5 pots in the same way as the experimental pots, saturating them with water, allowing water to flow freely under gravity from the bottom of the pot while the top of the pot was covered to prevent surface evaporation. The pots were weighed regularly over a period of days until the rate of weight loss was only very slight. This was considered the weight at field capacity.

Experimental pots were arranged in a random block design. Temperature loggers were inserted to the same depth in the 1st, 3rd and 5th pots for each treatment; 12 loggers in total.

Like commercial seeds, the seeds in this experiment were planted at a depth of 7 mm. In each pot 12 seeds were planted evenly spaced in pairs in a ring 25 mm from the rim of the plant pot.

For one week after planting pots were weighed and surface irrigated daily to maintain field capacity, this was to aid germination and initial seedling establishment. After seven days the cotyledons were showing on the majority of seedlings. At this point seedlings were thinned to leave the six most uniform evenly spaced seedlings (figure 1a) remaining and treatments commenced. The experimental unit was one pot containing six radish plants.

The four treatments were: G1 irrigated daily, G2 irrigated every two days, G3 irrigated every four days and G4 irrigated every eight days (table 1). At irrigation the pots were watered back to the weight at field capacity as calculated in a preliminary experiment. During irrigation pots were surface watered (figure 1b) using a squeezable water bottle with a fine nozzle to ensure an even distribution of water over the surface without damaging seedlings (figure 1b).

There were six experimental and three destructive harvest pots for each treatment, giving nine pots per treatment, 36 pots in total containing a total of 216 radish plants, 144 of which were experimental plants.
Table 1 Summary of treatments used in Experiment 1

<table>
<thead>
<tr>
<th>Treatment Number</th>
<th>Irrigation Frequency</th>
<th>Replication</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>1 day</td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G2</td>
<td>2 day</td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G3</td>
<td>4 day</td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G4</td>
<td>8 day</td>
<td>6 pots containing 6 plants each</td>
</tr>
</tbody>
</table>

The pots were not covered during the experiment. Compensation was made for the increasing weight of the radish in the pots by performing destructive harvests twice a week on Tuesday and Friday.

Figure 1a Pot containing 6 evenly spaced seedlings which have been thinned from 12 plants. Figure 1b Pots were surface irrigated on the weighing scales to the correct GWC.

Leaf number was counted and stomatal conductance was measured on the oldest leaf of each plant with an AP4 porometer (Delta-T Devices Ltd., Cambridge, UK) before harvest. Preliminary experiments showed taking porometer readings from the oldest leaf gave the most consistent results.

All plant pots were watered to field capacity at least 2 hours prior to harvest. At harvest the radish hypocotyls were washed in water at ambient temperature, examined for splits, the width and length of the hypocotyl to the first root hair measured and the red root plus hypocotyl measured using callipers. The radish were then defoliated, the white roots removed and the remaining radish was reweighed, the third lightest radish from each pot.
was dried at 105°C for 48 hours to calculate the dry biomass at harvest and the remaining 5 radish from each pot were put into a labelled cryovac bag to simulate commercial packaging and moved to a controlled environment cabinet for 7 days. The third lightest radish was chosen to be dried because it was considered this would be representative of the pot by being close to the median weight; choosing the largest or the smallest radish would have risked selecting non-representative outliers.

After 7 days of storage the radish were weighed again and the number of splits counted. The water content was calculated post-storage by drying all radishes at 105°C for 48 hours.

**Growth summary**

Seeds were planted on 13.03.2012, treatments commenced on 20.03.2012, plants were harvested and moved to storage on 13.04.12 and storage was terminated on 20.04.2012. Plants were grown for 31 days.

**Results**

**Environmental growth and storage conditions**

In the glasshouse the mean temperature was 18°C with a range of 35°C to 4°C. The mean relative humidity was 54% ranging between 93% and 15%.

The controlled environment cabinet achieved an average temperature of 2.8°C with a range between 5.2°C and -0.8°C. The average relative humidity was 70.3% with a range between 100% and 12.6%.

**Effect of treatments on soil temperature**

Differences in irrigation frequency in this experiment did not result in any significant differences (data not shown) in soil temperature; there were no significant differences in temperature between pots of different treatment groups. Therefore, any differences observed in the radish plants were not due to a difference in the temperature of the growing medium.

**Effect of treatments on soil water content**

Fluctuations in soil moisture of different magnitudes were created by different irrigation frequencies. Figure 2 shows the average daily volumetric water content VWC calculated from the gravimetric water content for each treatment group. It should be noted that soil water content is impossible to determine exactly in a non-destructive way with current technology and therefore, this graph is only a representation of the soil water content for the whole pot. The exact values will be a range around each point and will not be homogenous.
throughout the pot. As a result of water being added to the surface during irrigation one would expect the fluctuations in VWC (%) to be greatest at the surface of the compost mix around the radish hypocotyl. Despite this a clear pattern can be seen; G1 which was irrigated daily shows steady water content only fluctuating slightly around field capacity whereas G4 which was irrigated every 8 days shows large changes in water content. The peaks and troughs for G2, G3 and G4 increase as the experiment progresses due to increasing plant size within the pots and increased transpiration and water consumption.

![Figure 2](image)

**Figure 2** Average soil volumetric water content for pots irrigated at different frequencies (n=6) calculated from the gravimetric water content using bulk density.

**Table 2.** Average volumetric water content calculated from the gravimetric water content for pots in each treatment group.

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>Max VWC (%)</th>
<th>Min VWC (%)</th>
<th>Mean VWC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 1 day</td>
<td>21.6</td>
<td>19.6</td>
<td>20.7</td>
</tr>
<tr>
<td>G2: 2 day</td>
<td>21.5</td>
<td>17.9</td>
<td>19.9</td>
</tr>
<tr>
<td>G3: 4 day</td>
<td>21.6</td>
<td>13.4</td>
<td>18.1</td>
</tr>
<tr>
<td>G4: 8 day</td>
<td>21.5</td>
<td>6.5</td>
<td>15.2</td>
</tr>
</tbody>
</table>

**Effect of treatments on splitting**

There was no significant difference in the number of splits between treatment groups at harvest (P=0.912) (figure 3) and there was only one additional split radish after storage which was in G2 (data not shown). Although the results are not significant there is a trend in the data both at harvest and after storage; greater fluctuations in soil moisture content correlate with a greater number of splits. G1, which was watered the most frequently and...
therefore experienced the smallest fluctuation in soil moisture, has the least number of splits whereas G4, which had the largest fluctuation in soil moisture, has the largest number of splits. In G2 and G3, which had smaller fluctuations in soil moisture than G4 but larger fluctuations than G1, the average number of split radish per pot was between the average G1 and G4 values. Though not all treatments fit this pattern (G3 had larger fluctuations in soil moisture than G2), on average there are less split radishes in G3 than G2 both at harvest and after storage. The average numbers of split radish post storage are slightly lower after storage than at harvest because one radish was removed from each pot at harvest to calculate the bulk density at harvest and not put into controlled environment storage.

**Figure 3** Mean (± SE) number of split radish per pot at harvest (n=6, df=15) bars represent standard error for each treatment.

**Significant effects of treatments**

There was a significant difference in stomatal conductance, water content at harvest, water content after storage, total length at harvest, number of leaves at harvest, total weight at harvest, trimmed weight at harvest and trimmed weight after storage between treatment groups (Table 3). There was no significant difference (P=0.974) in radish dry weight at harvest or after storage (P=0.615) (data not shown) suggesting the increase in weight was due to an increased water content rather than dry matter.
Table 3 Significant effects of irrigation frequency on radish growth at harvest (n=6).

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>Stomatal Conductance (mmol m^{-2} S^{-1})</th>
<th>Water content (%)</th>
<th>Length (mm)</th>
<th>Number of leaves</th>
<th>Total weight (g)</th>
<th>Trimmed weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 1 day</td>
<td>124.67^a</td>
<td>92.55^a</td>
<td>69.6^a</td>
<td>6.583^a</td>
<td>21.96^b</td>
<td>14.81^b</td>
</tr>
<tr>
<td>G2: 2 day</td>
<td>75.83^{ab}</td>
<td>92.27^{ab}</td>
<td>68.2^a</td>
<td>6.000^a</td>
<td>19.91^{ab}</td>
<td>14.15^{ab}</td>
</tr>
<tr>
<td>G3: 4 day</td>
<td>57.00^{ab}</td>
<td>90.81^{ab}</td>
<td>67.0^a</td>
<td>5.972^a</td>
<td>16.71^a</td>
<td>11.74^{ab}</td>
</tr>
<tr>
<td>G4: 8 day</td>
<td>27.65^b</td>
<td>90.57^b</td>
<td>57.3^a</td>
<td>5.944^a</td>
<td>15.54^a</td>
<td>10.47^a</td>
</tr>
</tbody>
</table>

SEM (15 DF) 0.467 3.05 0.1568 1.126 1.010
CV (%) 1.3 11.4 6.3 14.9 19.3
P 0.008 0.017 0.047 0.032 0.004 0.027

Table 4 Significant effects of irrigation frequency on radish growth after storage (n=6).

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>Water content after storage (%)</th>
<th>Trimmed weight after storage (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 1 day</td>
<td>92.47^a</td>
<td>12.82^b</td>
</tr>
<tr>
<td>G2: 2 day</td>
<td>92.44^a</td>
<td>12.12^{ab}</td>
</tr>
<tr>
<td>G3: 4 day</td>
<td>91.98^a</td>
<td>10.05^{ab}</td>
</tr>
<tr>
<td>G4: 8 day</td>
<td>90.39^b</td>
<td>9.32^a</td>
</tr>
</tbody>
</table>

SEM (15 DF) 0.821
CV (%) 18.2
P 0.020 0.026

A significant difference (P=0.046) was observed in the average VWC (%) of the pots of split and non-split radish (figure 4). Pots containing radish which split had higher average VWC than pots containing radish which did not split.
Pattern of split

Splitting in *Raphanus sativus* ‘Rudi’ appears to be anisotropic; 96% of splits after storage (data not shown) were along the radial longitudinal axis.

**Experiment 2: Investigating the effects of water potential on cracking in European radish (Raphanus sativus cv. Rudi)**

**Materials and methods**

Radish seeds were initially planted in 362 x 227 mm seed tray inserts (Ref: C24, LBS Horticulture Ltd., Lancashire) containing John Innes No. 2 growing medium, at a rate of 1 seed per cell. Like commercial seeds, the seeds in this experiment were planted at a depth of 7 mm. They remained in seed trays for 7 days to enable seedling establishment.

After 1 week the most uniform seedlings were transferred to 4.2 L pots containing a 1:1 mix of horticultural sand and John Innes No. 2 growing medium. In each pot 6 uniform seedlings were transplanted and planted with equal spacing in a ring 25 mm from the rim of the plant pot.

The seedlings were transplanted to pots which had been uniformly filled 2 weeks previously. After the pots had been prepared they were left to dry in the glasshouse for 2 weeks, at this point the pots contained on average 20% VWC, this was used as they driest treatment. At field capacity the pots contained on average 26% VWC, therefore to avoid stress due to saturation the treatments were 24%, 23%, 21% and 20% VWC. The weight at field capacity had previously been calculated as explained for experiment 1. The weights for the other pots
were calculated using the known weight and water content at field capacity. Destructive harvests were performed twice a week to enable the increasing weight of the radish plants to be added to the weight of the pots at the different water contents.

Experimental pots were arranged in a random block design. Relative humidity and temperature were logged in the glasshouse using TGP 4500 TinyTag logger.

Pots were weighed and surface irrigated twice a week on Tuesday and Friday to maintain the water content of the treatments.

The four treatments were: G1 24% VWC, G2 23% VWC, G3 21% VWC and G4 20% VWC. There were eight experimental and three destructive harvest pots for each treatment (table 5), giving 11 pots per treatment, 44 pots in total containing a total of 264 radish plants, 192 of which were experimental plants.

**Table 5** Summary of treatments used in Experiment 1

<table>
<thead>
<tr>
<th>Treatment Number</th>
<th>VWC (%)</th>
<th>Replication</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>24</td>
<td>8 pots containing 6 plants each</td>
</tr>
<tr>
<td>G2</td>
<td>23</td>
<td>8 pots containing 6 plants each</td>
</tr>
<tr>
<td>G3</td>
<td>21</td>
<td>8 pots containing 6 plants each</td>
</tr>
<tr>
<td>G4</td>
<td>20</td>
<td>8 pots containing 6 plants each</td>
</tr>
</tbody>
</table>

During irrigation pots were surface watered to the weight at the VWC for their treatment. Pots were irrigated using a squeezable water bottle with a fine nozzle to ensure an even distribution of water over the surface without damaging the seedlings.

The pots were not covered during the experiment. Compensation was made for the increasing weight of the radish in the pots by performing destructive harvests twice a week on Tuesday and Friday.
Figure 5 The maximum exposed hypocotyl width of the radish plants was measured with digital vernier callipers.

The width of the exposed hypocotyls was measured twice a week before irrigation using digital vernier callipers (figure 5). Radish plants were grown until more than 50% of radish in that treatment were 30 mm in diameter or greater, at which point they were harvested. This is in keeping with supermarket size requirements.

At harvest the radish hypocotyls were washed in water at ambient temperature, examined for splits, the width and length of the hypocotyl to the first root hair measured and the red root plus hypocotyl measured using callipers. The radishes were then defoliated, the white roots removed and the remaining radish was reweighed, they were then put into a labelled cryovac bag to simulate commercial packaging and moved to a Sanyo Versatile Environmental Test Chamber Model: MLR-351H for 14 days.

After storage the radish were again weighed and measured and the number of splits counted. They were then put in an oven at 105°C for at least 48 hours to calculate the dry biomass post-storage.

Growth summary

Seeds were planted on 21.05.2012 plants were transplanted and treatments commenced on 28.05.2012. G1 plants were harvested and moved to storage on 02.07.2012, G2 plants were harvested and moved to storage on 06.07.2012 and G3 and G4 plants were harvester and moved to storage on 09.07.2012. For G1 plants storage was terminated on 16.07.2012, for G2 it was terminated on 20.07.2012 and for G3 and G4 plants storage was terminated on 23.07.2012.
G1 were harvested after 39 treatment days, G2 were harvested after 43 treatment days, G3 and G4 were both harvested after 46 treatment days. Growth time was longer than commercially grown radishes which usually take 4 weeks. This was thought to be, in part due to treatments, but also possibly due to transplanting the radish at the start of the experiment.

**Results**

**Environmental growth and storage conditions**

The mean temperature was 18.2°C with a range of 42.4°C to 9.1°C. The mean relative humidity in the glasshouse was 69.2% ranging between 99.6% and 14.2%.

The growth cabinet achieved an average temperature of 2.07°C with a range between 8.4°C and -3.0°C. It achieved an average relative humidity of 77.6% with a range between 100% and 14.9%.

**Effect of treatments on soil water content**

Treatments successfully (table 6) created a difference in soil moisture between groups. The VWC did overlap between treatments but the average was different for each group. The amount of water lost between irrigations increased as the experiment progressed; this is thought to be due to the increasing size of the plants and more water being lost due to transpiration.

**Table 6** Range of VWC (%) for each treatment group before G1 was harvested

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 24%</td>
<td>19.7</td>
<td>24</td>
<td>13.0</td>
</tr>
<tr>
<td>G2: 23%</td>
<td>18.7</td>
<td>23</td>
<td>13.3</td>
</tr>
<tr>
<td>G3: 21%</td>
<td>17.4</td>
<td>21</td>
<td>10.5</td>
</tr>
<tr>
<td>G4: 20%</td>
<td>16.1</td>
<td>20</td>
<td>10.3</td>
</tr>
</tbody>
</table>

**Effects of treatments on splitting**

There was no significant difference in splits at harvest (p=0.755) (table 7, figure 6).
The additional number of splits which occurred post-harvest during storage was not significant (P=0.585) but there was a trend (figure 7) with the most additional splits occurring in treatments with the highest maximum VWC (%) and the least amount of additional splits in the treatments which had the lowest two maximum VWC (%).

**Figure 6** The average number of splits per pot at harvest for each treatment (n=8, d.f.=20, P=0.755) bars show the standard error for each treatment

**Figure 7** The Mean (± SE) number of addition split radish per treatment after storage (n=8, d.f.=20, P=0.585).

**Effect of treatments on radish growth**

Treatments had an effect on the speed to growth of the radish plants; treatment group G1 reached harvest size the most quickly after 43 days, G2 were of harvest size in the next quickest time at 47 days. G3 and G4 both took the longest time of 50 days to reach harvest
size. All treatments took longer than the usual growth time but this is thought to be due to disruptions from transplanting the radish seedlings at the beginning of the experiment.

There was a significant different (P=0.004) in the number of leaves at harvest between treatment groups. G1 had the least leaves at harvest, G4 had the second least number of leaves, G3 had the second most number of leaves and G2 had the most number of leaves at harvest.

There was no difference in the size or weight of the radish at harvest between treatment groups (table 7, 8).

Table 7 Measurements (mean) taken at harvest taken for each treatment group.

<table>
<thead>
<tr>
<th>AWC (%)</th>
<th>Number of leaves</th>
<th>Width (mm)</th>
<th>Total Length (mm)</th>
<th>Bulb Length (mm)</th>
<th>Total weight (g)</th>
<th>Bulb Weight (g)</th>
<th>Average number of splits per pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 24%</td>
<td>9.083&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.51&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.36</td>
<td>14.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.13&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>G2: 23%</td>
<td>10.375&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.95&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.425</td>
<td>14.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>G3: 21%</td>
<td>10.208&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>39.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.218</td>
<td>12.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>G4: 20%</td>
<td>9.979&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>29.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>39.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.679</td>
<td>13.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.63&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

SEM (21 DF) | 0.235 | 0.631 | 0.786 | 0.797 | 0.712 | 0.572 |
CV (%) | 1.5 | 4.6 | 2.8 | 4.6 | 10.6 | 23.2 |
P | 0.004 | 0.346 | 0.502 | 0.945 | 0.175 | 0.508 | 0.755 |
**Table 8** Measurements (mean) taken after storage for each treatment group.

<table>
<thead>
<tr>
<th>AWC (%)</th>
<th>Width after storage (mm)</th>
<th>Total Length after storage (mm)</th>
<th>Bulb Length after storage (mm)</th>
<th>Bulb Weight after storage (g)</th>
<th>Wet weight after storage (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: 24%</td>
<td>29.03a</td>
<td>39.28a</td>
<td>23.95a</td>
<td>12.05a</td>
<td>12.05</td>
</tr>
<tr>
<td>G2: 23%</td>
<td>29.00a</td>
<td>39.85a</td>
<td>24.22a</td>
<td>12.61a</td>
<td>12.61</td>
</tr>
<tr>
<td>G3: 21%</td>
<td>29.25a</td>
<td>32.81a</td>
<td>25.34a</td>
<td>10.27a</td>
<td>10.27</td>
</tr>
<tr>
<td>G4: 20%</td>
<td>28.85a</td>
<td>39.99a</td>
<td>25.74a</td>
<td>11.45a</td>
<td>11.45</td>
</tr>
<tr>
<td>SEM (21 DF)</td>
<td>0.773</td>
<td>0.705</td>
<td>0.616</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>5.8</td>
<td>5.0</td>
<td>10.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.987</td>
<td>0.154</td>
<td>0.245</td>
<td>0.076</td>
<td></td>
</tr>
</tbody>
</table>

**Experiment 3: Investigating the effects of irrigation timing on cracking in European radish (Raphanus sativus cv. Rudi).**

**Materials and methods**

Radish were grown in 4.2 L pots containing a 1:1 mix of horticultural sand and John Innes No. 2 growing medium. Before mixing the sand was air dried on trays in the glasshouse to make the mix as homogeneous as possible.

Pots were uniformly filled and consolidated then watered to the weight at field capacity. The weight at field capacity was calculated as has been previously described. Experimental pots were arranged in a random block design.

Like commercial seeds, the seeds in this experiment were planted at a depth of 7 mm. In each pot 12 seeds were planted evenly spaced in pairs in a ring 25 mm from the rim of the plant pot.

For one week after planting pots were weighed and surface irrigated to maintain field capacity, this was to aid germination and initial seedling establishment. After seven days the cotyledons were showing on the majority of seedlings. At this point seedlings were thinned to leave the six most uniform evenly spaced seedlings remaining and treatments commenced. The experimental unit was one pot containing six radish plants.
For the purposes of this experiment the radish plants were grown for 5 weeks. In week 1 all plants were watered to field capacity to allow germination and establishment. After this, plants were given treatments for 2 weeks. All plants were irrigated twice a week on Tuesday and Friday. G1 was watered to field capacity for both the first and second halves of the experiment. G2 was watered to field capacity for the first half of the experiment then given deficit irrigation for the second half of the experiment. G3 was given deficit irrigation for the first half of the experiment then watered to field capacity for the second half of the experiment. G4 was given deficit irrigation for both halves of the experiment (table 9). Under deficit irrigation plants were irrigated with 25% of the water lost due to evapotranspiration since the last irrigation. All plants were watered to field capacity at the end of week 3 before the second half of the experiment.

There were six experimental and two destructive harvest pots for each treatment, giving eight pots per treatment, 32 pots in total containing a total of 192 radish plants, 144 of which were experimental plants.

**Table 9** Summary of treatments used in Experiment 3

<table>
<thead>
<tr>
<th>Treatment Number</th>
<th>Irrigation</th>
<th>Replication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 2-3</td>
<td>Weeks 4-5</td>
</tr>
<tr>
<td>G1</td>
<td>FC</td>
<td>FC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G2</td>
<td>FC</td>
<td>Deficit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G3</td>
<td>Deficit</td>
<td>FC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 pots containing 6 plants each</td>
</tr>
<tr>
<td>G4</td>
<td>Deficit</td>
<td>Deficit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 pots containing 6 plants each</td>
</tr>
</tbody>
</table>

Pots were irrigated using a squeezable water bottle with a fine nozzle to ensure an even distribution of water over the surface without damaging the seedlings.

The pots were not covered during the experiment. Compensation was made for the increasing weight of the radish in the pots by performing destructive harvests twice a week on Tuesday and Friday.

At harvest the radish hypocotyls were washed in water at ambient temperature, examined for splits, the width and length of the hypocotyl to the first root hair measured and the red root plus hypocotyl measured using callipers. The radishes were then defoliated, the white roots removed and the remaining radish was reweighed. The radishes were put into a labelled cryovac bag to simulate commercial packaging and moved to a Sanyo Versatile Environmental Test Chamber Model: MLR-351H.
After 14 days of storage the radish were weighed again and the number of splits counted. The water content was calculated post-storage by drying all radishes at 105°C for 48 hours.

**Growth summary**

Radish plants were grown for 35 days. Seeds were planted on 30.07.2012 treatments commenced on 06.08.2012 plants were harvested and moved to storage on 03.09.2012 storage was terminated on 17.09.2012.

**Results**

**Environmental growth and storage conditions**

In the glasshouse the mean temperature was 20.4°C with a range of 43.5°C to 7.6°C. The mean relative humidity was 68.1% ranging between 99.0% and 17.1%.

The cabinet achieved an average temperature of 4.2°C with a range between 6.5°C and 3.5°C. It had an average relative humidity of 94.8% with a range between 100% and 90.6%.

**Effect of treatments on soil water content**

Treatments successfully created a difference in the VWC. G1 and G2 had higher water content in weeks 2 and 3 then G1 and G3 had the highest water contents in weeks 4 and 5. VWC was slightly lower for the second half of the experiment. This is thought to be due to increased plant size and increased transpiration.

**Table 10** Range of VWC (%) for each treatment group in the first and second treatment

<table>
<thead>
<tr>
<th></th>
<th>Week 2-3</th>
<th>Week 4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average VWC (%)</td>
<td>Maximum VWC (%)</td>
</tr>
<tr>
<td>G1: FC/FC</td>
<td>20.6</td>
<td>23.2</td>
</tr>
<tr>
<td>G2: FC/D</td>
<td>20.4</td>
<td>23.2</td>
</tr>
<tr>
<td>G3: D/FC</td>
<td>16.1</td>
<td>20.5</td>
</tr>
<tr>
<td>G4: D/D</td>
<td>15.8</td>
<td>20.5</td>
</tr>
</tbody>
</table>

**Effects of treatments on splitting**

There was no significant effect of irrigation timing on splitting in radish at harvest (P=0.240) or after storage (P=0.161). However, there was a trend with G3, which received deficit irrigation for the first two weeks and then irrigation to field capacity for the final two weeks,
appearing to have less splitting on average per pot than the other treatments which were all similar in their rates of splitting on average per pot (figure 8).

![Figure 8 Mean (± SE) number of split radish per pot at harvest (n=6, df=15 P=0.240).](image)

There were three additional split radishes after storage; one in G2 and two in G4.

**Effect of treatments on radish growth**

Irrigation timing significantly affected radish growth in terms of number of leaves (P<0.001), width (P<0.001), total length (P<0.001), hypocotyl length (P<0.001), total weight (P=0.002) and trimmed weight (P<0.001) at harvest. Irrigation timing also significantly affected the yield in terms of wet weight (P=0.002), total length (P<0.001), hypocotyl length (p=0.016) and width after storage (P<0.001). The weight of the radish after storage was significantly different due to both significantly different water contents (P=0.001) between treatments and a significant difference in dry biomass (P<0.001). Plants which were irrigated to field capacity in the last two weeks had the highest yields in terms of weight and size compared to plants which had deficit irrigation in the last two weeks.
Table 11 Measurements (mean) taken at harvest for each treatment group.

<table>
<thead>
<tr>
<th>AWC (%)</th>
<th>Number of leaves at harvest</th>
<th>Width at harvest (mm)</th>
<th>Total length at harvest (mm)</th>
<th>Hypocotyl length at harvest (mm)</th>
<th>Total weight at harvest (g)</th>
<th>Trimmed weight at harvest (g)</th>
<th>Trapped weight at harvest (g)</th>
<th>Average number of split radish per pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: FC/FC</td>
<td>6.00</td>
<td>30.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.12</td>
<td>25.12 (2.76)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>G2: FC/D</td>
<td>5.44</td>
<td>23.73&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45.97&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.74&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>13.54</td>
<td>13.54 (2.11)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.83</td>
<td></td>
</tr>
<tr>
<td>G3: D/FC</td>
<td>6.44</td>
<td>30.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>49.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.23&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>24.69</td>
<td>24.69 (2.67)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>G4: D/D</td>
<td>5.34</td>
<td>21.90&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.23</td>
<td>13.23 (1.99)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>SEM (15 DF)</td>
<td>0.131</td>
<td>0.86</td>
<td>1.068</td>
<td>0.873</td>
<td>0.0578</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>3.2</td>
<td>3.3</td>
<td>3.5</td>
<td>3.9</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>0.240</td>
<td></td>
</tr>
</tbody>
</table>

<sup>FC = Field Capacity, D= Deficit irrigation replacing 25% of water lost since previous irrigation</sup>

Table 12 Measurements (mean) taken after storage for each treatment group.

<table>
<thead>
<tr>
<th>AWC (%)</th>
<th>Width after storage (mm)</th>
<th>Total length after storage (mm)</th>
<th>Hypocotyl length after storage (mm)</th>
<th>Wet weight after storage (g)</th>
<th>Dry biomass after storage (g)</th>
<th>Water content after storage (%)</th>
<th>Trapped weight after storage (g)</th>
<th>Average number of split radish per pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1: FC/FC</td>
<td>30.76&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.763&lt;sup&gt;c&lt;/sup&gt;</td>
<td>94.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>G2: FC/D</td>
<td>24.74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>27.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.633&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>91.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>G3: D/FC</td>
<td>29.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.54&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.735&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>93.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>G4: D/D</td>
<td>23.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.529&lt;sup&gt;a&lt;/sup&gt;</td>
<td>91.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.83</td>
<td></td>
</tr>
<tr>
<td>SEM (15 DF)</td>
<td>0.842</td>
<td>0.865</td>
<td>0.891</td>
<td>0.0287</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>3.0</td>
<td>3.1</td>
<td>2.6</td>
<td>11.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.016</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.161</td>
<td></td>
</tr>
</tbody>
</table>

<sup>FC = Field Capacity, D= Deficit irrigation replacing 25% of water lost since previous irrigation</sup>
Experiment 4: Investigating the different cracking susceptibility of different radish (Raphanus sativus) cultivars.

Materials and methods

Experiment 4 investigated the splitting susceptibility of different cultivars. Cultivars were; Rudi, Celesta F1 and Topsi. Celesta F1 is a variety currently grown commercially and it thought to crack less than other varieties, Rudi is a cultivar which is grown commercially and is thought to crack more than Celesta F1. Topsi is purported to have a thin skin which may affect its splitting rate; Hartz, 2005 found removal of the periderm reduced susceptibility to cracking in carrot. Potentially a thin skin on the radish would have a similar effect.

For this experiment radishes were grown in the conditions thought most likely to cause splitting as indicated by preliminary and previous experiments so the splitting susceptibility of different cultivars could be investigated. Radishes were grown in 4.2 L pots containing John Innes No. 2; preliminary experiments showed compost alone had higher water retention at the soil surface than a 1:1 mix of John Innes No. 2 and sand (data not shown). It is thought water retention at the soil surface around the hypocotyl may influence splitting.

Pots were uniformly filled then watered to the weight at 95% field capacity. The weight at field capacity was calculated as has been previously described. Experimental pots were arranged in a random block design.

Like commercial seeds, the seeds in this experiment were planted at a depth of 7 mm. In each pot 12 seeds were planted evenly spaced in pairs in a ring 25 mm from the rim of the plant pot.

For one week after planting pots were weighed and surface irrigated three times to maintain field capacity, this was to aid germination and initial seedling establishment. After seven days the cotyledons were showing on the majority of seedlings. At this point seedlings were thinned to leave the six most uniform evenly spaced seedlings remaining; the experimental unit was one pot containing six radish plants.

For the purposes of this experiment the radish plants were grown for 4 weeks. All plants were given the same irrigation regime for the duration of the experiment; three times a week to 95% field capacity. There were eight experimental and three destructive harvest pots for each treatment, giving 11 pots per treatment, 33 pots in total containing a total of 198 radish plants, 144 of which were experimental plants.
Pots were irrigated using a squeezable water bottle with a fine nozzle to ensure even distribution of water over the surface without damaging the seedlings.

The pots were not covered during the experiment. Compensation was made for the increasing weight of the radish in the pots by performing destructive harvests three times a week.

At harvest the radish hypocotyls were washed in water at ambient temperature, examined for splits, the width and length of the hypocotyl to the first root hair measured and the red root plus hypocotyl measured using callipers. The radishes were then defoliated, the white roots removed and the remaining radish was reweighed. The radish were put into a labelled cryovac bag to simulate commercial packaging and moved to a Sanyo Versatile Environmental Test Chamber Model: MLR-351H.

After 9 days of storage the radish were weighed again and the number of splits counted. The water content was calculated post-storage by drying all radishes at 105°C for 48 hours.

**Growth summary**

Seeds were planted on 26.10.12, seeds were thinned on 02.11.12, plants were harvested and moved to storage on 23.11.12, and radishes were removed from storage on 03.12.12.

**Results**

Data collection is still on going for this experiment. Once data has been collected and summarised, comparisons between cultivars should enable splitting susceptibility and characteristics of different cultivars to be determined.

**Discussion**

**Experiment 1**

If total weight, number of leaves, trimmed hypocotyl weight, hypocotyl length and hypocotyl width are considered components of growth, then radishes which were most frequently
irrigated grew the greatest and the radishes which were irrigated least frequently grew least. These results correlate with the work of Bokhtiar et al (2001) who found Radish ‘Tasaki Mula’; a long white tropical radish variety grew the most under their most frequent irrigation regime, where plants were watered to field capacity every 10 days and they grew the least under no irrigation. The smaller size of radish irrigated less frequently suggests lower turgor pressure due to water deficit. Turgor pressure is known to regulate both cell division and enlargement in plants generally (Kirkham et al. 1972) and specifically in radish (Joyce et al. 1983). Having a water deficit for a period of time would reduce turgor and therefore reduce growth during this period. The plants which were irrigated the least frequently would have had the longest periods of deficit and therefore the longest periods with reduced cellular expansion and division.

A significant difference in the average pot VWC (%) (P=0.046) of the plants which split and those which did not split was observed. Higher average water content was found in the pots with radish which split. Further investigation is required to determine if it is factors associated with the frequency of irrigation combined with average pot water content or average pot water content which affect splitting; G1 which split most received the greatest amount of water and G4 which split the least received the least amount of water.

**Experiment 2**

Watering the radish plants at the same frequency to different VWC did not result in any significant differences in splitting at harvest (P=0.755) or in any significant differences in the amount of additional splitting post-harvest (P=0.585). However, there was a trend with the treatment which received the highest maximum VWC having the greatest number of additional splits and the plants in the treatments which receives the lowest maximum VWC (%) having the least number of additional splits post-harvest.

**Experiment 3**

Irrigation in the last two weeks appears to determine width at harvest and after storage, weight at harvest and after storage and the water content after storage, as there was a significant difference between G1 and G3 when compared to G2 and G4 but no significant difference between G1 and G3 which were watered to field capacity in the last two weeks or G2 and G4 which had deficit irrigation in the last two weeks.

Irrigation over the lifetime of the radish appears to affect the number of leaves, the total length, the hypocotyl length at harvest and the dry biomass. The total length at harvest was significantly less in the radish with deficit irrigation throughout the experiment. The total length at harvest was not significantly different between the other groups.
Experiment 4

Experiment on going. Once the experiment has finished and the data collected and analysed comparisons between cultivars should indicate which cultivars are more resistant to splitting.

Conclusions

- The least amount of splitting tends to occur with most frequent irrigation and the greatest amount of splitting occurs with the most infrequent irrigation.
- Highest yields are associated with frequent irrigation. However, these plants also received the most water.
- The average water content of pots did not have an effect on splitting at harvest.
- Radish with a higher maximum VWC tended to split more during storage.
- Average water content affected growth rate.
- High VWC at the surface during early growth tended to result in more splits, as did deficit irrigation during later growth.
- VWC in the final two weeks affects yield. Watering to field capacity compared to deficit irrigation resulted in a greater yield.
Technology Transfer

December 2011  Poster presented at Harper Adams University College Post-graduate symposium

December 2011  Presentation at Harper Adams University College Post-graduate symposium

February 2012  Grower visit – G’s Growers Barway and Feltwell

July 2012  Poster presented at HDC Studentship Conference

September 2012  Presentation at PEPg Ecophysiology Workshop

October 2012  Grower meeting and presentation of work to date – G’s Growers Barway

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References

