Horticultural Fellowship Awards

Interim Report Form

Project title:	Working with the industry to develop the next generation of technical staff for the UK horticulture industry through a Summer Research Programme.
Project number:	CP 87
Project leader:	Dr Jim Monaghan
Report:	Annual report, March 2013
Previous report:	Annual report, May 2012
Fellowship staff:	Josie Brough (Technical support) Dr Paul Hand (Associate) Prof Dave Pink (Associate);
Location of project:	Harper Adams University
Industry Representative:	N/A
Date project commenced:	8 July 2011 (back dated 1 April 2011)
Date project completed (or expected completion date):	31 March 2016

DISCLAIMER

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.

[Name]
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Report authorised by:

[Name]
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Progress Against Objectives and Annual Milestones

Objectives

Objective	Original Completion Date	Actual Completion Date	Revised Completion Date
1. Recruit a minimum of 15 undergraduates from UK Higher Education Institutions to complete applied experiments in horticultural crop production and agronomy.	31/03/2016		
2. Deliver a minimum of 15 small-scale research projects for the industry.	31/03/2016		
3. Publicise the approach and outputs of the programme to the industry, Further Education and Higher Education Institutions.	31/03/2016		
4. Leverage additional funding for follow up projects.	31/03/2016		

Summary of Progress

The second year of the Summer Research Programme (SRP) was successful. Three UK undergraduates were selected; from Bangor University, Exeter University and Royal Holloway, University of London. The students undertook three separate research projects at HAU linked to FP Matthews, Bulrush Horticulture Ltd and G's, and also worked together on a number of on-going crop research experiments at HAU. Each student prepared and gave a presentation of their research to the representatives from HDC. The students also made a number of visits to businesses including strawberry, leafy salad, field vegetable, protected salad, tree and ornamental producers and a breeding company.

More detailed reports of each of the three projects are appended to this report and a brief summary of each project is included here. The experiments are numbered sequentially throughout the fellowship and experiments 4-6 are reported here.

Experiment 4 - Does biochar addition improve growth of young containerised apple trees?

Rachel Carpenter (Bangor University)

Biochar (charred biomass) is produced by heating biomass in a zero-oxygen environment to temperatures of 250°C or greater, yielding energy-rich gases and liquids which can be used in other processes, and a solid charcoal, or biochar (Downie *et al*., 2009).

There is increasing evidence that biochar has some beneficial effects when added to soils. Its highly porous structure can retain water and capture some soil nutrients and release them over time to the surrounding substrate. Some work has shown that biochar incorporation in substrates can reducing N leaching and potentially increase N use efficiency (Prendergast-Miller *et al*., 2011).

This project was developed with FP Matthews and Bulrush Horticulture Ltd who were interested in studying any growth effects of adding biochar to the growing substrate of containerised apple trees. Four commercial and semi-commercial mixes with the same base substrate but different sources of nutrients were studied (Table 1).

Ten bare rooted 1 year maiden *Malus domestica* cv Falstaff on MM 111 root stock (supplied by FP Matthews) were planted in 4 litre containers per treatment.

Table 1. *Treatments studied in Experiment 4*

Substrate mix	Nutrient source	Biochar (% v/v)	Treatment code
Mix 1 Base fertiliser and FTE	Base + CRF	0	Mix 1 -Biochar
Mix 2 Ground mineral base	Base + Urea	0	Mix 2 -Biochar
Mix 3 Base fertiliser and FTE	Base + Urea	0	Mix 3 -Biochar
Mix 4 Loam base with SSP	Base + Urea	0	Mix 4 -Biochar
Mix 1 Base fertiliser and FTE	Base + CRF	20	Mix 1 +Biochar
Mix 2 Ground mineral base	Base + Urea	20	Mix 2 +Biochar
Mix 3 Base fertiliser and FTE	Base + Urea	20	Mix 3 +Biochar
Mix 4 Loam base with SSP	Base + Urea	20	Mix 4 +Biochar

CRF = controlled release fertiliser; FTE = fritted trace elements; SSP = single super phosphate

Soil moisture readings showed differences between the mixes which became smaller when biochar was added. The amount of leaf chlorophyll was similar with most mixes but there was an indication that Mix 2 was providing less nitrogen. Extension growth was measured weekly and plant growth generally was improved in the mixes containing biochar but the response was not uniform (Figure 1).

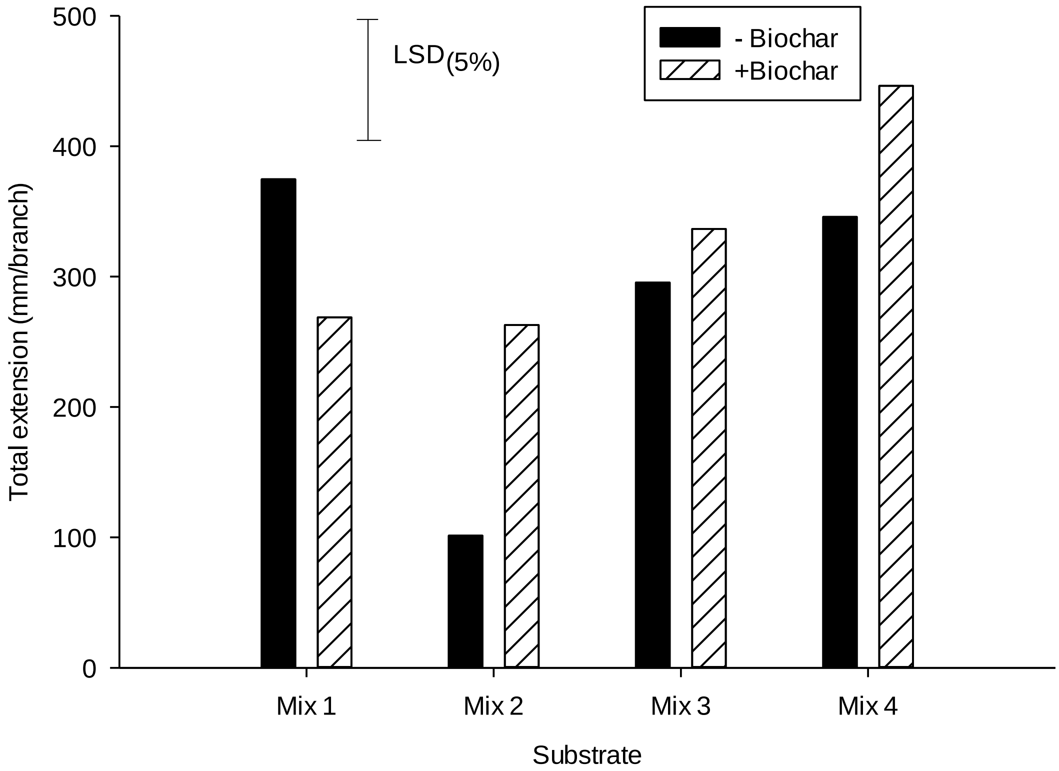

Figure 1. *Total accumulated extension growth over the course of Experiment 4*

Key findings

- Substrate mix affected plant growth. Mix 2 had the least extension growth and the palest older leaves. Mix 4 had the greatest extension growth.
- This work has not established the underlying cause of the reduced growth in Mix 2 although there are indications that the mix was too dense and may have lacked N supply.
- Biochar addition increased plant growth overall. This response was not consistent with each substrate mix and further work will be needed to study the underlying causes of these differing responses.

Experiment 5 - Does peat-free growing substrate significantly affect strawberry growth and yield?

John Vaughan-Hirsch (Royal Holloway, University of London)

There is strong pressure on growers to reduce the use of peat in commercial horticulture. This pressure comes from the government, most recently from the Natural Environment White Paper published in June 2011. This outlines the Government's aims to eliminate horticultural peat use in the public sector by 2015, in the amateur market by 2020 and in the professional sector by 2030 (Defra, 2013). In response to government initiatives and pressure from NGO's, multiple retailers require growers to reduce and eliminate peat use in fresh produce production.

Peat has been an ideal substrate for soil-less strawberry production but in the last 10 years coir, derived from coconut husks, has been used increasingly as a dilutant and replacement for peat in soil-less production systems. A number of industries, including the automotive sector, are also increasing their use of coir. As the demand for coir increases, the availability of consistently high quality coir can be variable and prices are rising. Some growers are considering wood fibre based substrates as an alternative to both peat and coir. Wood fibre substrates can have the benefit of being produced in Europe but are also in demand for other uses, particularly building materials and energy production.

This trial was established to compare the performance of coir and wood fibre substrate (WFS) as blends in table-top 60 day strawberry production.

Four commercial reduced peat/peat-free substrates were supplied by Bulrush Horticulture Ltd in 1 metre strawberry bags (Table 2). The bags were a mix of one or more of coir, peatand wood fibre based substrate.

Table 2. *Substrate mixes studied in Experiment 5*

	Substrate mix
1	100% coir
2	50:50 coir:peat
3	50:50 WFS:peat
4	50:50 coir:WFS

Each bag was planted with 10 Elsanta 18-20mm crowns (Hargreaves Plants Ltd, Spalding) in a double row formation and fertigated following commercial practice.

The average fruit yield was not significantly different between substrates and produced approximately 1.6 kg fruit per bag (Figure 2). The plants were of a similar size for each substrate as well.

The 50:50 WFS:peat mix was consistently the driest substrate, significantly drier than 100 % coir at most dates. The three substrates containing coir maintained relatively similar moisture contents through the trial and consequently the average moisture contents were similar with 100 % coir, 50:50 coir:peat and 50:50 coir WFS having 50.5, 46.7 and 48.1 % moisture. The 50:50 WFS:peat mix had an average moisture content of 41.6 %, significantly lower than the other three substrates.

The fertigation run-off showed that pH and EC both rose more rapidly over time with the WFS substrate but not at a level that would cause concern.

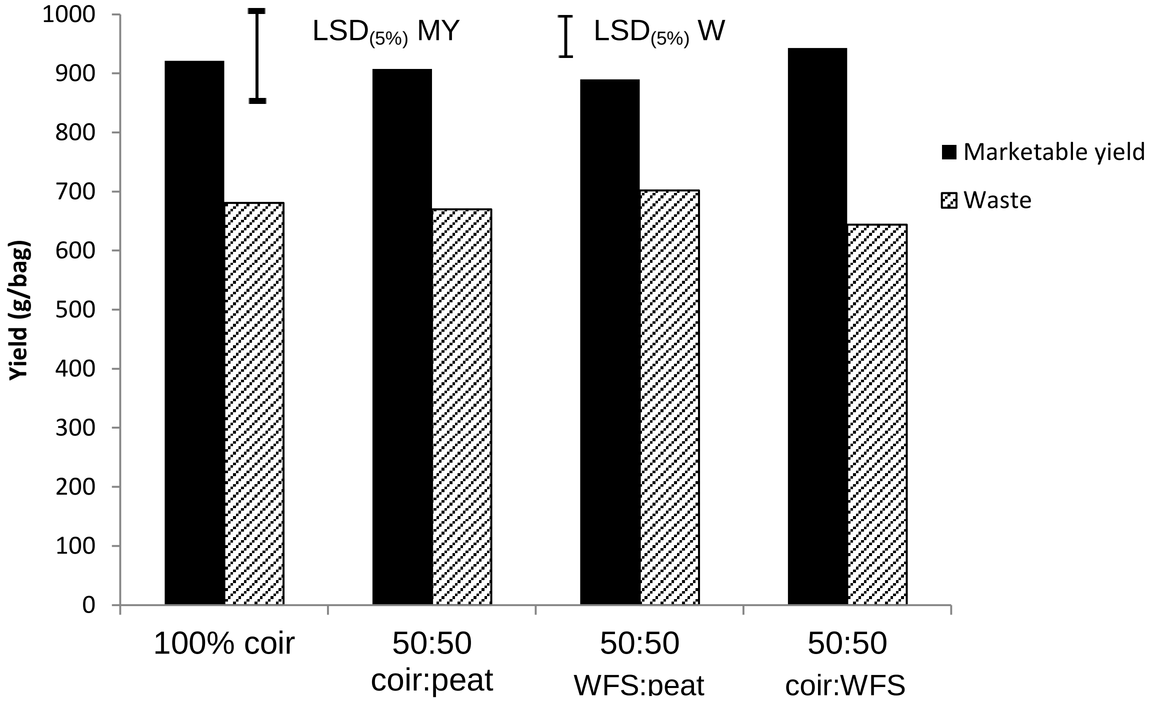

Figure 2. *Total accumulated yield and marketable waste per bag in Experiment 5. Bars show LSD (5%) for marketable yield (MY) and waste (W), WFS= Wood fibre substrate*

Key findings

- All mixes produced acceptable commercial plants.
- Irrigation regimes will need fine-tuning for the WFS mixes and attention to the pH rise and EC over time may be needed.

Experiment 6 - Does irrigation regime change the rooting pattern of onion sets?

Lara Boucher (Exeter University)

Improved monitoring of both soil and crop water status and the development of variable water application technology (i.e. Precision Irrigation) has the potential to be used in new irrigation management techniques that manipulate plant growth rather than just prevent the crop from being exposed to a level of water stress that leads to economic loss. Plants are plastic in their response to reduced water availability, changing root and shoot growth, and the relationship between soil water status and the threshold for irrigation is not constant through crop development. If it were possible to routinely schedule irrigation from plant responses rather than direct measurements of soil water status, this may allow greater precision in matching irrigation quantity to crop need (Monaghan *et al*., 2013).

Drying soil can stimulate deeper rooting (Sharp and Davies, 1985) and there may be benefits in reduced irrigation at the early, less yield-sensitive, stages of crops that produce deeper-rooting plants, enabling access to water lower in the soil profile and conferring greater resilience to midsummer drought events.

Two treatments were imposed on the rhizotrons: Wet Treatment where 100% of the weight loss between weighing (i.e. water loss) was replaced as water three times a week and Moderate Treatment 2 where 50% of the weight loss between weighing was replaced as water three times a week between day 0-18 after which they received no more water. The treatments were randomised within the greenhouse and Onion sets (cv Sturon), supplied by Greens of Soham, were planted on 19 July 2012 with three sets per rhizotron subsequently thinned to two per rhizotron after 10 days.

Soil moisture measurements showed that the onions did not start to dry the soil in the rhizotrons until near the end of the trial. The summer of 2012 was unusually cool and overcast and even in a glasshouse plant growth was reduced. The distribution of roots through the soil profile was similar for both treatments and no clear differences were observed in rooting pattern (Figure 3). Thirty six days after planting the onion top growth and roots were removed and weighed fresh and dry and in all measures the wet treatment produced more growth. This difference was only significant in the shoot dry weight.

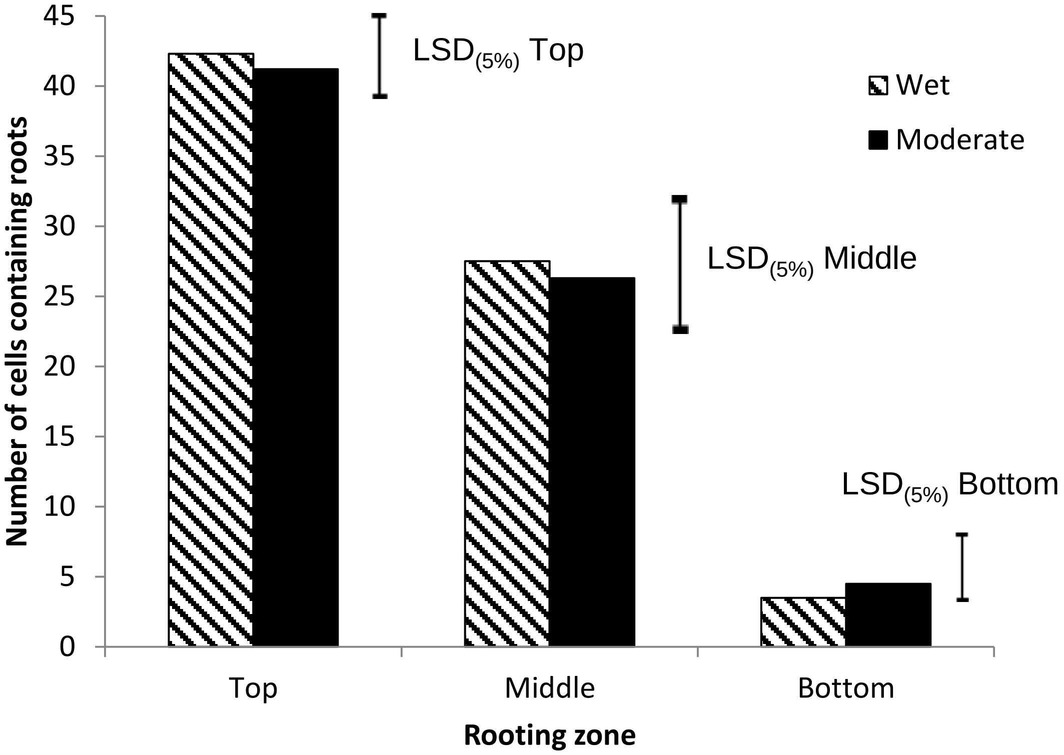

Figure 3. *Root distribution through the rhizotron at the end of Experiment 6*

Key findings

- Onion sets do not root deeply in the first 5 weeks of growth.
- Onion sets do not start to use significant amounts of water in the first 36 days after planting.
- Deficit irrigation treatments cannot be imposed early in the growth of onion sets.

Visits by students

Six businesses hosted visits by the students: PDM (lettuce), Lower Reule Farm (strawberries), Elsoms Seeds (seeds), G's (field vegetables), FP Matthews (trees and HONS), Cornerways Nursery (tomatoes).

Informal feedback from the students was very positive and two of the three students undertook research in fresh produce crops for their final year research project. Of the three students one has applied for plant science PhD research, one has applied for MDS and one has been offered a graduate role in a fresh produce business.

The fellow aims to keep contact with all the SRP students to track later career choices.

Milestones

Annual Milestone	Original Completion Date	Actual Completion Date	Revised Completion Date
1. Select proposed project titles and outlines of work in agreement with Partner businesses and HDC Research Manager.	31/05/2012	31/05/2012	
2. Commence experimental work.	31/05/2012	31/05/2012	
3. Complete mail shots and selected visits to other institutions.	31/05/2012	31/05/2012	
4. Recruit SRP students	30/06/2012	30/06/2012	
5. SRP students start	01/07/2012	01/07/2012	
6. SRP students finish	20/09/2012	20/09/2012	
7. Research reported to HDC (end November)	31/03/2013	31/03/2013	

Milestones not being reached

N/A

Do remaining milestones look realistic?

Yes

Training undertaken

No training was undertaken by the Fellow in Year 2.

Expertise gained by Trainee

N/A

Other achievements in the last year not originally in the objectives

The Gatsby Summer School for high achieving Plant Scientists targeted at first year UK undergraduates (www.gatsbyplants.leeds.ac.uk) has linked to this programme as an opportunity for applied research experience.

Changes to Project

N/A

Are the current objectives still appropriate for the Fellowship?

No changes proposed.

GROWER SUMMARY

The second year of the Summer Research Programme (SRP) was successful. Three UK undergraduates were selected; one from Bangor University, Exeter University and Royal Holloway, University of London. The students undertook three separate research projects at HAU linked to FP Matthews, Bulrush Horticulture Ltd and G's, and also worked together on a number of on-going crop research experiments at HAU. Each student prepared and gave a presentation of their research to representatives from HDC. The students also made a number of visits to businesses including strawberry, leafy salad, field vegetable, protected salad, tree and ornamental producers and a breeding company.

More detailed reports of each of the three projects are appended to this report.

Headline

Three undergraduate students have successfully carried out crop production research projects in the Fresh Produce Research Centre at HAU.

Background

The recent Royal Society report and the Fruit and Vegetable Task Force report have both highlighted the shortage of applied technical expertise available to the UK horticulture industry. Reduction in government funding for applied horticulture research has led to a marked reduction in the pool of applied researchers available for employment in industry, research and advisory/agronomist roles. In addition the loss of many relevant crops focussed courses and modules from Universities have led to a marked shortage of opportunities for undergraduates to be exposed to, and trained in, applied research in horticulture crop production compared to 10-15 years ago. This limits the number of suitable candidates for technical roles in industry, research studentships, technical roles in universities or institutes, or agronomy and extension businesses.

We have launched a Summer Research Programme (SRP) based at Harper Adams University College (HAUC) and led by Jim Monaghan. The SRP will recruit three UK undergraduate students (and potentially seconded industry employees) each year. These students will then carry out applied agronomy/crop production research projects within the Fresh Produce Research Centre and be supported by other research staff associated with the centre.

Summary

See appendices.

Financial Benefits

N/A

Action Points

See appendices.

Knowledge and Technology Transfer

The SRP was presented at the:

HDC Board – HAU (13/02/2013)

HDC Protected Edibles panel meeting – HAU (05/03/2013)

A webpage and facebook site has been set up for the SRP and contain videos of each project.

http://www.harper-adams.ac.uk/initiatives/fresh-produce-research-centre/

https://www.facebook.com/HAUFreshProduce

Glossary

N/A

References

Defra (2013) *Peat, growing media* [On-line] Defra. Available from: http://www.defra.gov.uk/food-farm/crops/peat/ [Accessed 22 February 2013].

Downie, A., Crosky, A., Munroe, P. (2009), Physical Properties of Biochar, in Lehmann, J. and Joseph, S. (editors), *Biochar for Environmental Management*, Earthscan, London: 13-32.

Monaghan, J.M., Daccache, A., Vickers, L.H., Hess, T.M., Weatherhead, E.K., Grove, I.G., Knox, J.W. (2013) More 'crop per drop': constraints and opportunities for precision irrigation in European agriculture. *J Sci Food Agric* 93: 977–980

Prendergast-Miller, M.T., Duvall, M., Sohi, S.P. (2011) Localisation of nitrate in the rhizosphere of biochar-amended soils. *Soil Biology and Biochemistry* 43(11) 2243–2246

Sharp, R.E., Davies, W.J. (1985) Root growth and water uptake by maize plants in drying soil*. J Exp Bot* 36:1441–1456

Appendices

A detailed report of the three experiments are appended to this report:

Appendix 4

Experiment 4 - Does biochar addition improve growth of young containerised apple trees?

Appendix 5

Experiment 5 - Does peat-free growing substrate significantly affect strawberry growth and yield?

Appendix 6

Experiment 6 - Does irrigation regime affect rooting pattern of onion sets?

4 Experiment 4 - Does biochar addition improve growth of young containerised apple trees?

4.1. Background

Biochar (charred biomass) is produced by heating biomass in a zero-oxygen environment to temperatures of 250°C or greater, yielding energy-rich gases and liquids which can be used in other processes, and a solid charcoal, or biochar (Downie *et al.,* 2009).

Biochar is being studied for two potential uses in UK agriculture and horticulture: a) as a long-term store (sink) for carbon, reducing carbon emissions, and b) as a soil/substrate improver.

There is increasing evidence that biochar has some beneficial effects when added to soils. Its highly porous structure can retain water and capture some soil nutrients and release them over time to the surrounding substrate. Some work has shown that biochar incorporation on substrates can reducing N leaching and potentially increase N use efficiency (NUE) (Prendergast-Miller *et al*., 2011).

This project was developed with FP Matthews and Bulrush Horticulture Ltd Ltd who were interested in studying any growth effects of adding biochar to the growing substrate of containerised apple trees. Four commercial and semi-commercial mixes with the same base substrate but different sources of nutrient were studied. The two research questions were:

1) Does substrate mix significantly affect plant growth?

2) Does addition of biochar change plant responses to substrate mix?

4.2. Materials and methods

The experiment was carried out at Harper Adams University College during the summer of 2012. The experiment was managed by Rachel Carpenter who was a Summer Research Placement student from Bangor University.

The project was linked to FP Matthews and Bulrush Horticulture Ltd.

4.3. Treatments

Table 1. *Treatments studied in Experiment 4*

Substrate mix	Nutrient source	Biochar (% v/v)	Treatment code
Mix 1 Base fertiliser and FTE	Base + CRF	0	Mix 1 -Biochar
Mix 2 Ground mineral base	Base + Urea	0	Mix 2 -Biochar
Mix 3 Base fertiliser and FTE	Base + Urea	0	Mix 3 -Biochar
Mix 4 Loam base with SSP	Base + Urea	0	Mix 4 -Biochar
Mix 1 Base fertiliser and FTE	Base + CRF	20	Mix 1 +Biochar
Mix 2 Ground mineral base	Base + Urea	20	Mix 2 +Biochar
Mix 3 Base fertiliser and FTE	Base + Urea	20	Mix 3 +Biochar
Mix 4 Loam base with SSP	Base + Urea	20	Mix 4 +Biochar

CRF = controlled release fertiliser; FTE = fritted trace elements; SSP = single super phosphate

4.1.1. Trial set up

A 10 m x 10 m area of land adjacent to the CERC offices was chosen for the trial site. It was bounded by an established hedge on one side and partial shelter from the CERC buildings and a smaller hedge was provided on 2 other sides. Prior to setting up the trial the land was flattened with a roller and surface weeds were sprayed off with an application of Roundup. Ten lengths of 1 m wide double Geotex membrane were pegged down and a row of plastic interlocking pathway blocks was laid on top of each row of membrane to provide a level weed free base for the trees. Support post were driven in to each end of the row with a double wire stretched between them provided support for the trees.

Eight treatment mixes were used for this experiment (Table 4.1). Three base mixes were supplied by Bulrush Horticulture Ltd (Mixes 1, 3 and 4), Mix 2 was supplied by FP Matthews. Charcoal that had been produced in 2012 from thinnings and coppicing of mixed birch, sycamore and alder (HAU) was then added to half the volume of the four base mixes at a rate of 20 % by volume using the following method to provide four further treatments. Two x 80 litre bags of each base mix were emptied onto the floor of the tractor shed then ten x 4 litre pots of charcoal were added. The mixing was done with a shovel then the compost was labelled and put into black tubs ready for planting the trees.

Ten bare rooted 1 year maiden *Malus domestica* cv Falstaff on MM 111 root stock (supplied by FP Matthews) were potted 1 May 2012 by adding a small amount of compost to the base of a 4 litre pot. The tree was stood on the compost in the centre of the pot with the roots as low into the pot as possible and compost was gradually added to cover the roots, being well pressed down around the roots to remove air, the pot was then filled to a level of within 5 cm of the top and the 80 guard trees were planted in the same way. After potting up all trees were labelled then thoroughly water with a lance and arranged pot thick on the site for several days before being laid out in a fully randomised design of 8 rows of 10 trees. The experimental trees *cv* Red Falstaff, were bounded by an outside edge of 2 guard trees of 1 year maiden *Malus domestica* cv James Grieve on MM 111 root stock (supplied by FP Matthews).

Two irrigation circuits were set up with an individual line arrange alongside each row of trees and a single outlet dripper was placed in each pot. Initially the irrigation was set manually to wet up the substrates then an automatic irrigation program was set up to irrigate twice a day for 10-15 minutes.

A biweekly liquid application of Urea (1.3 g N/pot in 200 ml) was applied to all trees planted in the medium lacking CRF (Plantacote 12-14).

A spray program to control apple scab and aphids was establish which consisted of an alternate tank mix of Systhane 300 ml/Ha and Captan 1 kg/Ha alternated with Topas 400 ml/Ha and Captan 1 kg/Ha every two weeks until the end of the season.

Weeds were controlled on the site with regular grass cutting and manual weed removal. Eight weeks after potting up the number of fruit excluding fallen fruit was recorded then removed from the trees.

4.1.2. Recordings

Duplicate soil moisture readings were taken twice a week by inserting a DT HH2 moisture meter probe (Delta T Devices, Cambridge) into the compost either side of each tree.

Leaf chlorophyll readings were taken weekly using a Minolta Spad 502 chlorophyll meter were taken from a young fully expanded leaf and a mature fully expanded leaf on the same branch.

Extension growth was measured weekly. The same two branches on each tree were used for all recordings and labelled with top, middle and bottom. Growth was measured from start of new growth to end of last leaf.

The effect of biochar on pH and EC of run-off was monitored on 10 litre pots of base substrate (Mix 3 with and without biochar at 20 % v/v). Three pots of each mix were saturated with tap water and left for 2 days to drain under gravity. The pots were saturated again and the run-off collected and analysed.

4.1.3. Statistics

All plant measurements were analysed by 2-way ANOVA using Genstat 13th Edition. Run-off water was analysed using t-test.

4.2. Results

The season was unusually wet and cool which prevented the application of some routine scab treatments but the trees were generally healthy with no significant disease observed on the foliage.

4.2.1. Substrate moisture content

Substrate Moisture content varied over the experiment (Figure 4.1). Mix 2 -Biochar consistently had the highest moisture content and from day 75 Mix 3 -Biochar had the lowest moisture content.

When averaged over all readings the base substrate (i.e. averaged with and without biochar) had a significant main effect ($p<0.001$) on substrate moisture content. Mix 2 (47.5 %) was significantly wetter than Mix 4 (40.7 %) > Mix 1 (38.4 %) > Mix 3 (35.7 %). Mix 3 was also significantly drier than Mix 4. There was no main effect of biochar overall but the addition of biochar to Mix 2 (Mix 2 +Biochar) significantly reduced the average moisture content from 50.4 % to 44.6 % (Figure 4.2).

4.2.2. Leaf Chlorophyll

Leaf chlorophyll content of both the older mature leaves and young expanding leaves showed no clear pattern of response over time (data not presented). Overall the young leaves had less chlorophyll with an average SPAD value of 28.0 compared to 45.8 for the older leaves.

When averaged over the experiment a significant effect ($p<0.001$) of base substrate was observed for the older leaves. Mix 2 had paler leaves with a SPAD value of 44.1

significantly less than Mix 3 (48.5). Mix 3 had darker leaves than all three other mixes, but Mix 1 and 4 were similar in leaf chlorophyll content with a SPAD value of 45.2 and 45.5 respectively.

Biochar also had a significant main effect for both the older (p=0.008) and the young leaves (p=0.033) with the addition of 20 % biochar giving lower SPAD values. There was no interaction between base mix and biochar for either young or older leaves.

4.2.3. Extension growth

Extension growth was greatest in the top branches and least in the bottom branches with an average extension per branch over the experiment of 46, 63 and 193 mm for the bottom, middle and top branches respectively.

4.2.3.1. Bottom branches

There was a significant main effect of base substrate (p=0.014) on bottom branch extension and the bottom branches grew least in the base substrate of Mix 2 regardless of biochar content. Mix 2 plants grew an average 22 mm, significantly less than the other mixes which grew 50, 53 and 62 mm for Mix 4, 1 and 3 respectively.

There was no main effect of biochar or interactions between substrate and biochar on the growth of the lower branches (Figure 4.3a).

4.2.3.2. Middle branches

There was a significant (p=0.003) main effect of substrate on middle branch extension with Mix 2 having the least growth with an average of 37 mm, significantly less than Mix 1 (73 mm) and Mix 4 (92 mm). Mix 3 had moderate growth with an average of 54 mm which was significantly less than Mix 4 also.

Biochar had no main effect but there was a significant interaction (p=0.001) observed between mixes and biochar; adding biochar to Mix 1 significantly reduced extension growth but significantly increased extension growth in Mix 4 (Figure 4.3b).

4.2.3.3. Top branches

Substrate had a significant main effect (p<0.001) on the extension of the top branches. Mix 2 had the least growth (123 mm) significantly less than the other mixes. Mix 4 had the greatest extension growth with 254 mm and this was significantly more than the other mixes. Mix 1 and 3 had moderate and similar extension growth of 196 and 200 mm respectively.

There was no main effect of biochar but as with middle branches the pattern of response to biochar treatment differed significantly (p=0.015) in Mix 2 where the addition of biochar led to more than double the extension growth with 173 mm compared to 73 mm for Mix 2 +Biochar and Mix 2 –Biochar, respectively(Figure 4.3c).

4.2.3.4. Total growth

When the extension at each location was added together there was a significant main effect of substrate ($p<0.001$) with Mix 2 having significantly less growth (182 mm) than the other mixes. Mix 4 had significantly more growth (396 mm) than the other mixes and Mix 3 and 1 had similar growth with 316 and 322 mm respectively.

Biochar had a small but significant main effect ($p=0.05$) with the addition of biochar giving on average more growth with 279 mm compared to 329 mm.

There was a significant interaction ($p=0.003$) between biochar addition and base substrate. Adding biochar to Mix 1 led to a significant decrease in growth but adding biochar to Mix 2 and 4 led to a significant increase in growth (Figure 4.4). A small increase was also observed with Mix 3.

4.2.4. Run-off

The tap water used had a pH of 7.17 and an EC of 0.43 mS. The addition of biochar significantly ($p<0.001$) raised the pH of the run-off from 5.11 to 5.95 but there was no significant effect on EC (Table 4.2).

***Table 4.2**. pH and EC of run-off from Mix 3 with and without biochar at 20% v/v.*

	- Biochar	+ Biochar	Significance (n=3)
pH	5.11	5.95	<0.001
EC	2.88	3.17	NS

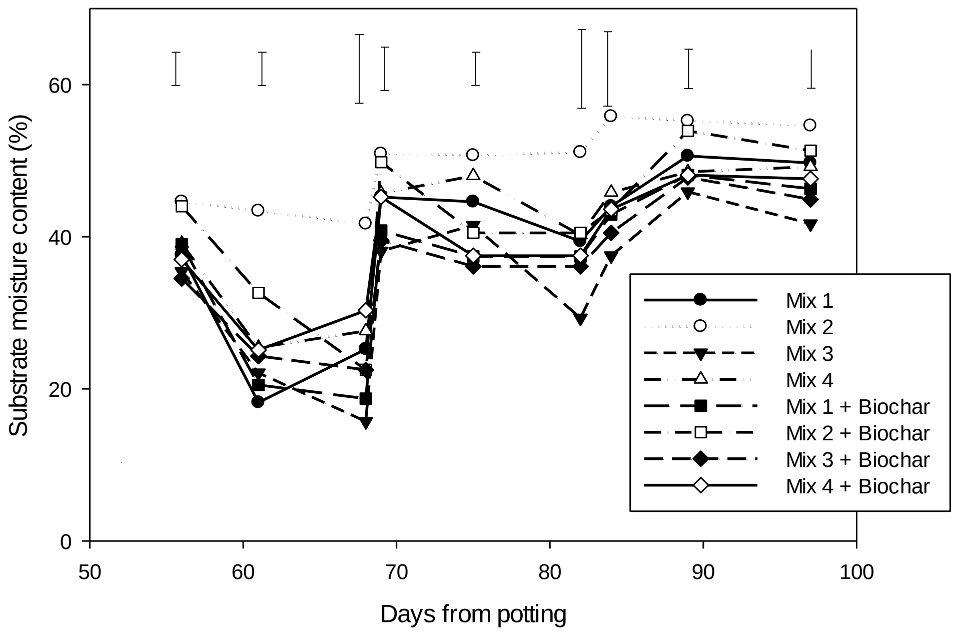

Figure 4.1. Substrate moisture content over time. Bars = $LSD_{(5\%)}$.

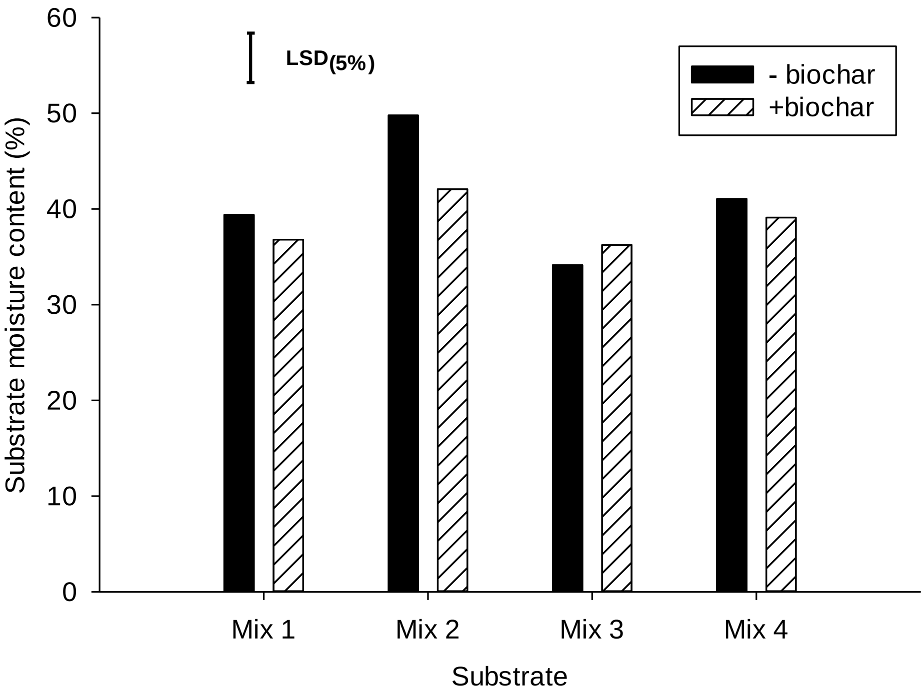

Figure 4.2. *Average substrate moisture content.*

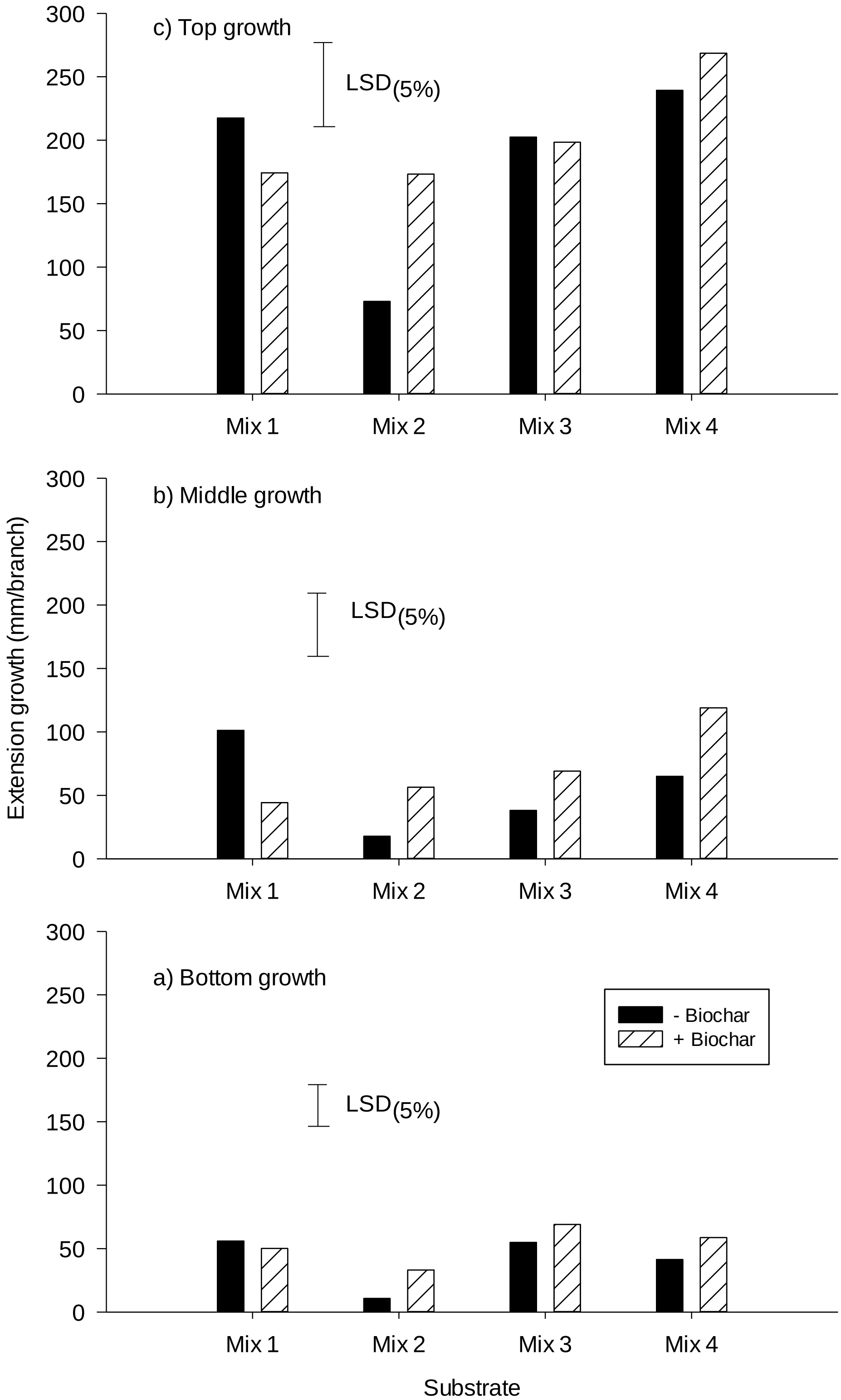

Figure 4.3. *Accumulated extension growth for a) bottom, b) middle and c) top branches over the course of the experiment.*

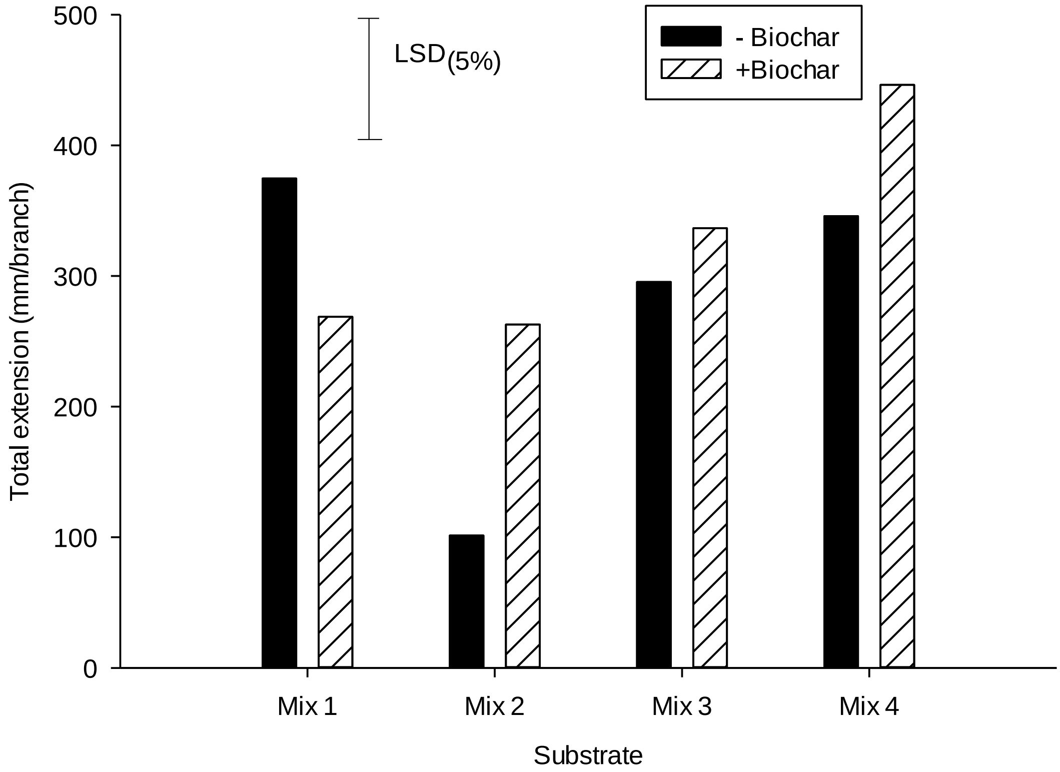

***Figure 4.4** Total accumulated extension growth over the course of the experiment.*

4.3. Discussion

Did substrate mix significantly affect plant growth?

The mixes supplied were commercial and semi-commercial trial mixes. The exact analysis of each mix is not known.

The substrate mix had a significant main effect on plant growth (i.e. averaged for mixes regardless of addition of biochar) and total extension growth was greatest with Mix 4 and least with Mix 2; Mix 1 and 3 had similar total extension growth. A similar pattern was observed in growth of bottom, middle and top branches.

The reduced growth in Mix 2 was associated with significantly paler older leaves suggesting that N may have been limited in this mix. Where N supply is limited older leaves may senesce earlier in order to retranslocate N, maintaining N supply to the new leaf growth

There was also a main effect of substrate on moisture content with Mix 2 being significantly wetter than Mixes 4, 1 and 3. The mix also appeared to be denser in the container (but this was not quantified).

Nutrients supplied by CRF were capable of producing plants of similar quality to Urea fertigation with Mixes 1 and 3 having similar overall growth.

More work is needed to understand the cause of the reduced growth in Mix 2. Mix 2 held the greatest proportion of water but produced the least growth and the palest older leaves. In contrast, these two factors do not explain the performance of Mix 4 as the greatest growth observed with Mix 4 was associated with moderately wet substrate and moderately green leaves.

Did biochar addition change plant response to substrate mix?

Over all four mixes there were two significant responses to biochar: the older leaves were paler, and the total extension growth increased. The paler leaves could be explained by a dilution of the nutrient supply in the substrate by incorporating biochar at 20%. All four mixes had base nutrients incorporated and Mix 1 also had CRF incorporated. As well as physically diluting the substrate, biochar also locks up some elements, particularly N and between these two effects nutrient supply may have been reduced when biochar was added.

A small scale run-off trial did not see any effect on total EC but pH was significantly raised by the addition of biochar suggesting that biochar could also change nutrient availability where it is limited by pH (e.g. Fe). Further studies are needed to establish the change in nutrient availability to plants in container systems incorporating biochar.

There were some different responses to biochar between mixes. Moisture content was similar with and without biochar with Mix 1, 3 and 4 but the addition of biochar significantly reduced moisture content in Mix 2. This may be due to the denser Mix 2 being opened up and draining more freely.

Addition of biochar reduced total extension growth in Mix 1 but increased it significantly in Mix 2 and 4 and had a small but non-significant increase in Mix 3. Mix 1 was the only mix to include CRF (Plantacote 12-14), which release nutrients over time, the other mixes received biweekly fertigation with Urea. There are a number of explanations that may account for the observed response: the CRF was diluted by 20% addition of biochar as discussed above, and/or some of the nutrients may have been absorbed by the biochar. The cooler season may also have reduced the release of nutrients from the CRF. Further studies are needed to establish whether this response to biochar is consistent in substrates incorporating CRF.

In summary, Mix 1 showed strong growth that was reduced by biochar; Mix 2 showed reduced growth but this was improved by addition of biochar; Mix 3 had strong growth tha was not affected by biochar; and Mix 4 showed strong growth and this was increased by biochar.

4.4. Conclusions

- Substrate mix affected plant growth. Mix 2 had the least extension growth and the palest older leaves. Mix 4 had the greatest extension growth.
- This work has not established the underlying cause of the reduced growth in Mix 2 although there are indications that the mix was too dense and may have lacked N supply.
- Biochar addition increased plant growth overall. This response was not consistent with each substrate mix and further work will be needed to study the underlying causes of these differing responses.

4.5. References

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Downie, A., Crosky, A., Munroe, P. (2009), Physical Properties of Biochar, in Lehmann, J. and Joseph, S. (editors), *Biochar for Environmental Management*, Earthscan, London: 13-32.

5 Experiment 5 - Does peat-free growing substrate significantly affect strawberry growth and yield?

5.1. Background

There is strong pressure on growers to reduce the use of peat in commercial horticulture. This pressure comes from the government, most recently from the Natural Environment White Paper published in June 2011. This outlines the Government's aims to eliminate horticultural peat use in the public sector by 2015, in the amateur market by 2020 and in the professional sector by 2030 (Defra, 2013). In response to government initiatives and pressure from NGO's, multiple retailers require growers to reduce and eliminate peat use in fresh produce production.

Peat has been an ideal substrate for soil-less strawberry production but in the last 10 years coir, derived from coconut husks, has been used increasingly as a dilutant and replacement for peat in soil-less production systems. A number of industries, including the automotive sector, are also increasing their use of coir. As the demand for coir increases, the availability of consistently high quality coir can be variable and prices are rising. Some growers are considering wood fibre based substrates as an alternative to both peat and coir. Wood fibre substrates can have the benefit of being produced in Europe but are also in demand for other uses, particularly building materials and energy production.

This trial was established to compare the performance of coir and wood fibre (Forest Gold Plus) as blends in table-top 60 day strawberry production and asked the research question: does growing substrate affect marketable yield of table-top strawberries?

5.2. Materials and methods

The experiment was carried out at Harper Adams University during the summer of 2012. The experiment was managed by John Vaughan-Hirsch who was a Summer Research Placement student from Royal Holloway, University of London.

The project was linked to Bulrush Horticulture Ltd.

5.2.1. Treatments

Four commercial reduced peat/peat-free substrates were supplied by Bulrush Horticulture Ltd in 1 metre strawberry bags (Table 5.1). The bags were a mix of one or more of coir, peat and a wood fibre based substrate (WFS).

	Substrate mix
1	100% coir
2	50:50 coir:peat
3	50:50 WFS: peat
4	50:50 coir: WFS

Table 5.1. *Substrate mixes studied in Experiment 5.*

5.2.2. Trial set up

A 27 m x 10 m x 3 m polytunnel sited at CERC, Harper Adams University College, supplied with mains power and potable irrigation water was used for the 2012 HDC summer project strawberry trial. The lower edges and ends of the tunnels were fitted with black butterfly netting to allow for ventilation but prevent entry of airborne pests and the outside perimeter of the tunnel was further protected by a 50 cm mesh electric fence.

Prior to setting up the trial a 500 ml sample of irrigation water was sampled from Black Bridge pond and sent to MRN for testing with their standard irrigation suitability L003 package.

4 x 24 m lengths of ridged profile aluminium container floor board width 22 cm x 3 cm deep were supported at intervals by plinths of 5 breeze blocks to a height of 53 cm arranged lengthwise down the tunnel at a spacing of 1.6 m apart. A 20 mm irrigation line was attached with cable ties to one edge of each aluminium strip and the far end was doubled over and secured with a cable tie. The other ends were connected to an in-line Dosatron DI-16 and feed stock tank controlled by a Galcon 6054 DC 4S controller. The controller was set to irrigate each line for 4 x 5 minute events each hour. During vegetative growth Solufeed strawberry starter feed was used at a concentration of 1 kg/10 l diluted to 1:200 during an irrigation event, this was then changed for Solufeed SF-C at fruit formation used at the same rate.

The 4 treatments were randomised on each bench and prior to laying the bags on the benching each bag was agitated to break up any compaction from storage. They were then placed lengthwise on the bench and butted up to each other. Single-outlet drippers were then attached to the main irrigation line and 2 drippers were placed in each bag with equal spacing. An unplanted irrigated example of each medium was placed at the end of each bench to monitor water input and a plastic tray fitted with a spout draining into a container was placed under a planted example of each medium to monitor run off. A Tinytag data logger was placed in a slatted plastic cage and placed on bench 2 between bags 10 and 11 at canopy height and set to record temperature and humidity at 15 minute intervals throughout the duration of the experiment.

Each bag was planted with 10 Elsanta 18-20 mm crowns (Hargreaves Plants Ltd, Spalding) in a double row formation. After planting, the irrigation was set to constant for several days to thoroughly wet up the bags.

Once plants were established the following spray program was applied to control Botrytis, mildew and aphids.

For the first few weeks alternate sprays of Spruzit 2 l/ha and Amistar 1 l/ha were used. This was followed by a tank mix of Scala 2 l/ha and Nimrod 1.4 l/ha then the following week a tank mix of Scala 2 l/ha and Systhane 230 ml/ha. In the remaining weeks of the trial the following spays were applied weekly in the order given. Nimrod 1.4 l/ha, Systhane 230 ml/ha, Fortress 250 ml/ha, Fortress 250 ml/ha.

Weeds in the tunnel were controlled by regular manual hoeing and runners were regularly removed from plants by snipping them off to within 2 cm of the plant.

5.2.3. Recordings

The irrigation run-off from the planted example of each medium was sampled twice weekly and tested for pH and EC using a Jenway 4510 Conductivity meter and a Jenway 3505 pH meter.

Once plants had established, 3 replicate soil moisture readings were taken in between the drippers from the side of each bag using a Delta T HH2 moisture meter. The readings were taken every 3 to 4 days in the morning.

The date and number of the first red fruits per bags were recorded then 10 harvests of fully ripened fruit were done over an 11 week period at intervals of 3 to 4 days. At each harvest the fruits from all plants within a treatment bag were picked and graded as either good or waste and the weights recorded.

Weekly leaf chlorophyll readings using a Minolta Spad 502 chlorophyll meter were taken from an old fully expanded leaf and a young fully expanded leaf from each plant.

Weekly photographs of each treatment bag were also taken.

Four bags, one from each treatment, were placed on 1 m long trays which were angled to collect the run-off in containers connected to one corner. The containers were emptied on a Friday afternoon and the run-off accumulated over the weekend was analysed on Monday morning for pH and EC. Run-off was collected at four periods of time over the course of the experiment.

The field capacity of each medium was tested by filling three 10 l pots with each substrate and saturating with tap water. The pots were covered, left to drain under gravity for 72 hours and were weighed regularly. Field capacity was assumed after approximately 48 hours, when the weight of the pots was relatively constant. The substrate was removed, weighed wet and then oven dried at 80°C until dry allowing calculation of the water content at field capacity.

5.2.4. Statistics

All plant measurements were analysed by 1 way ANOVA using Genstat 13th Edition.

5.3. Results

The 2012 season was unusually cool and cloudy with reduced light levels as a consequence. There was no significant pest or disease damage to the crop.

5.3.1. Yield

The average fruit yield per bag was not significantly different producing 1.602, 1.616, 1.592 and 1.587 kg for 100 % coir, 50:50 coir:peat, 50:50 WFS:peat and 50:50 coir:WFS respectively. All four substrates produced similar accumulated yields of marketable and waste fruit (Figure 5.1). The pattern of yield was also similar for the substrates over the harvest period (data not presented).

5.3.2. Plant size

No significant difference between the substrates was observed for relative plant height at any measurement.

5.3.3. Leaf colour

There was no significant effect of substrate for leaf chlorophyll content measured using SPAD values at any date. The average SPAD value declined over the trial from 30.5 at day 34 to 28.1 at day 62. The average SPAD value was not significantly different for the four substrates and ranged from 29.6 to 30.1.

5.3.4. Substrate moisture

The substrates were capable of holding large amounts of water and the moisture content at field capacity was estimated as 85.2, 79.8, 82.8 and 83.4% for 100% coir, 50:50 coir:peat, 50:50 WFS:peat and 50:50 coir:WFS respectively.

Substrate moisture content in the planted bags varied significantly between substrates over the trial (Figure 5.2). After initially being the wettest bag the 50:50 WFS:peat mix was consistently the driest substrate, significantly drier than 100 % coir at most dates.

The three substrates containing coir maintained relatively similar moisture contents through the trial and consequently the average moisture contents were similar with 100 % coir, 50:50 coir:peat and 50:50 coir WFS having 50.5, 46.7 and 48.1 % moisture (Table 5.2). The 50:50 WFS:peat mix had an average moisture content of 41.6 %, significantly lower than the other three substrates.

5.3.5. Run-off

The fertigation solution had an average pH of 7.0 and EC of 1450 µS/cm.

The run-off from planted bags was collected 4 times. Although both the WFS containing substrates had a higher pH the average pH did not differ significantly between substrates (Figure 5.3). The average EC from the run-off was again higher in the WFS substrates and was significantly higher in the 50:50 WFS:peat substrate compared to the 100 % coir and 50:50 coir:peat substrates (Figure 5.4).

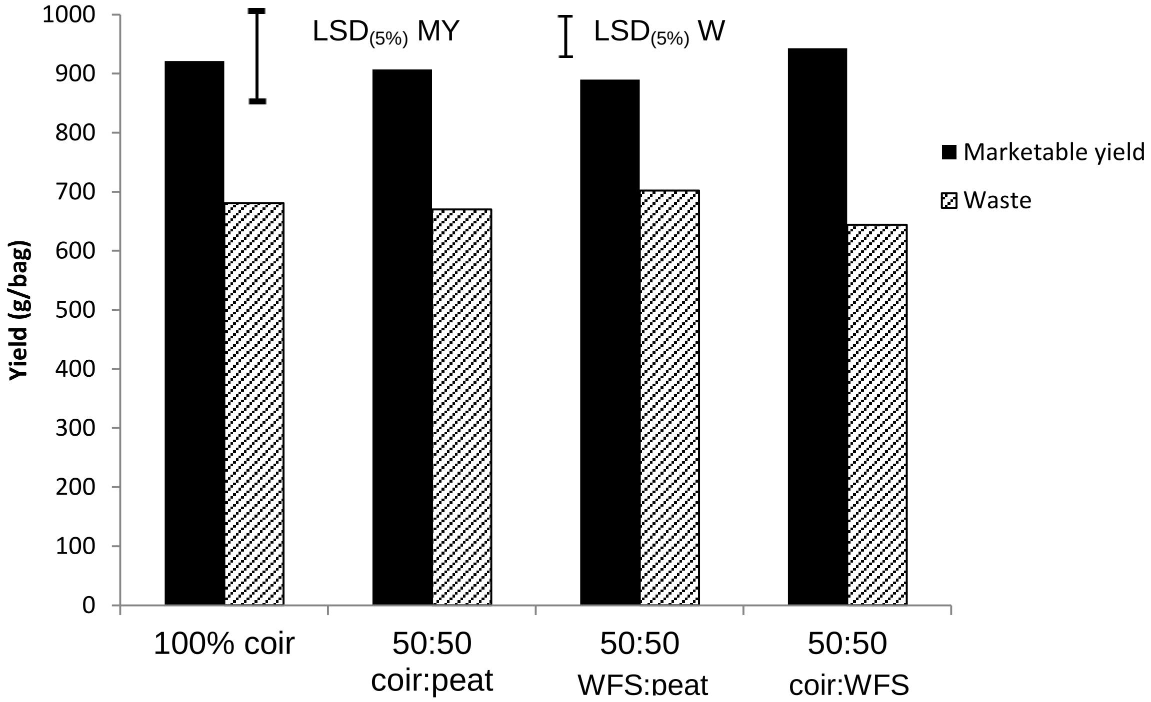

Figure 5.1. *Total accumulated yield and marketable waste per bag. Bars show $LSD_{(5\%)}$ for marketable yield (MY) and waste (W).*

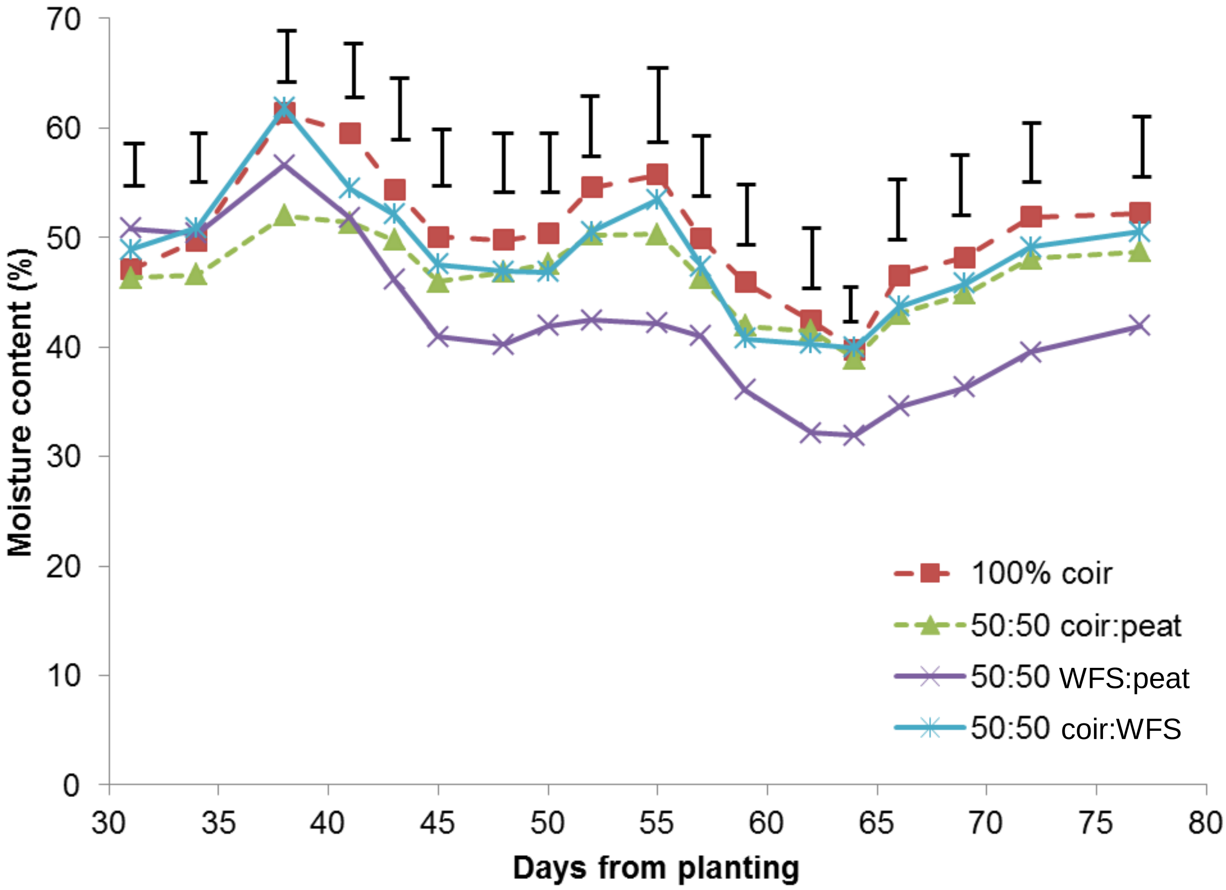

Figure 5.2. *Substrate moisture content over time. Bars show $LSD_{(5\%)}$.*

Table 5.2. *Average moisture content of the four substrates. Data derived from planted bags.*

Substrate	**Average SMC (%)**
100% coir	50.5
50:50 coir:peat	46.7
50:50 WFS:peat	41.6
50:50 coir:WFS	48.1
Mean	46.72
SE (n=20)	1.68
$LSD_{(5\%)}$	3.34

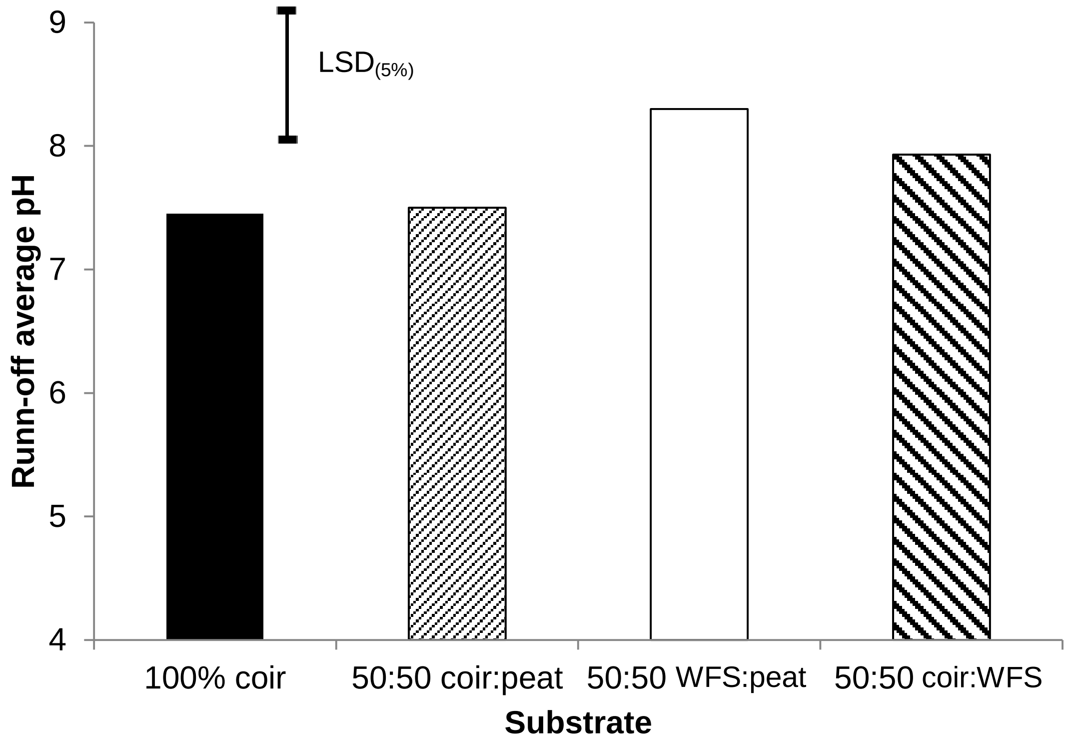

Figure 5.3. *Run-off pH averaged over four sample dates. Bar shows LSD$_{(5\%)}$.*

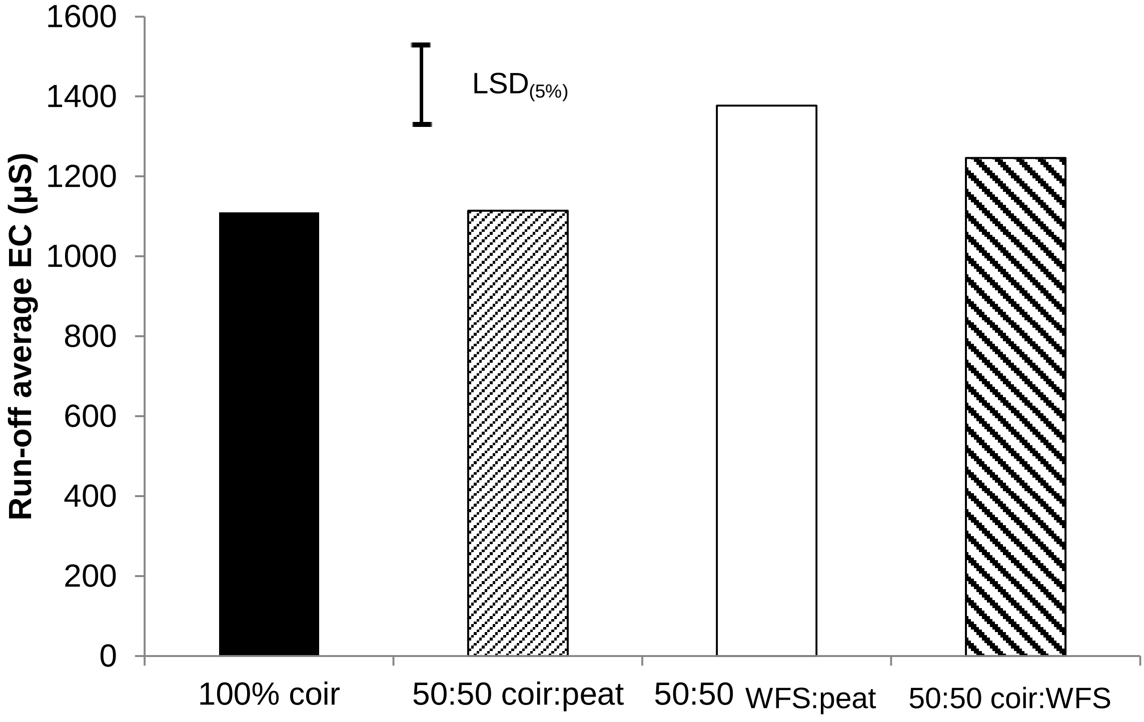

Figure 5.4. *Run-off EC averaged over four sample dates. Bar shows LSD$_{(5\%)}$.*

5.4. Discussion

Does growing substrate affect marketable yield of table-top strawberries?

All four substrate mixes produced healthy plants with similar yields both of marketable and class 2 yields. There were no differences in the growth of the plants in the different substrates with similar plant heights and leaf colours observed throughout the trial.

WFS drained more freely than the other components and, as a consequence, the moisture content of the WFS:peat bags was approximately 10% lower than the 100% coir bags. In this trial all the bags were irrigated with the same volume of water and further work will be needed to optimise irrigation regimes for the WFS mixes.

Fertigation run-off showed a general rise in pH and reduction in EC compared to the fertigation solution. The increase in run-off pH was more marked (but not significant) with the WFS:peat mix. A change in pH can affect the availability of some nutrients and acidification may be needed for these mixes to maintain optimum pH.

The higher EC with the WFS:peat mix may be explained by the greater proportion of fertigation that was draining from the bags or a leaching of salts from the substrates. Further work is needed to establish the cause of this response, although it should be noted that this response was not associated with any yield response with a 60 day crop, the performance of the substrate in the second year (as is common in many production systems) may be affected.

5.5. Conclusions

- All mixes produced acceptable commercial plants
- Irrigation regimes will need fine-tuning for the WFS mixes and attention to the pH rise and EC over time may be needed.

5.6. References

Defra (2013) *Peat, growing media* [On-line] Defra. Available from: http://www.defra.gov.uk/food-farm/crops/peat/ [Accessed 22 February 2013].

6 Experiment 6 - Does irrigation regime affect rooting pattern of onion sets?

6.1. Background

Improved monitoring of both soil and crop water status and the development of variable water application technology (i.e. Precision Irrigation) has the potential to be used in new irrigation management techniques that manipulate plant growth rather than just prevent the crop from being exposed to a level of water stress that leads to economic loss. Plants are plastic in their response to reduced water availability, changing root and shoot growth, and the relationship between soil water status and the threshold for irrigation is not constant through crop development. If it were possible to routinely schedule irrigation from plant responses rather than direct measurements of soil water status, this may allow greater precision in matching irrigation quantity to crop need (Monaghan *et al*., 2013).

Drying soil can stimulate deeper rooting (Sharp and Davies, 1985) and there may be benefits in reduced irrigation at the early, less yield-sensitive, stages of crops that produce deeper-rooting plants, enabling access to water lower in the soil profile and conferring greater resilience to midsummer drought events.

This work was set up in collaboration with G's to establish whether irrigation regime affects rooting pattern of onion sets.

6.2. Materials and methods

6.2.1. Trial set up

The experiment was carried out at Harper Adams University College during the summer of 2012. This experiment used 12 rhizotrons (80 cm x 30 cm x 4 cm) were filled with John Innes No.2 compost. The compost was sieved using a 5 mm sieve to remove any stones and large organic matter from the substrate that would affect the root distribution and growth. The rhizotrons were put together with 2 straps holding the cover on.

The rhizotrons were filled to the top with the compost, and then rocked from side to side 10 times to encourage the compost to settle, this allowed more compost to be placed inside. Again the rhizotron was rocked 5 times, repeating the filling and a final rocking of just 2 times before a final top up of compost. They were placed in white trays, lying up against the wooden stands at a 45°. Then 3500 ml of water was added to the compost and the rhizotrons were placed with the Perspex sheet facing up to reduce the amount of water leakage and encourage absorption into the profile.

The rhizotrons were watered and then the compost topped up after slumping. This watering was continued every three days with 200 ml of water for the next 7 days before planting.

The rhizotrons were weighed prior to planting, these weights were classed as field capacity for the experiment and irrigation was carried out to this weight on Monday, Wednesday and Friday. A weight loss of 0.1 kg equates to 100ml of water lost. the water was added to the surface, with the rhizotrons standing vertically to stop the compost slumping and shrinking away from the perspex sheet of the rhizotron. Water was measured in a 400ml beaker and half of the water was applied to each side of the sets, to allow for even distribution through the growing medium.

6.2.2. Treatments

Two treatments were imposed on the rhizotrons: Wet Treatment where 100% of the weight loss between weighing (i.e. water loss) was replaced as water three times a week and

Moderate Treatment 2 where 50% of the weight loss between weighing was replaced as water three times a week between day 0-18 after which they received no more water. The treatments were randomised within the greenhouse and Onion sets (cv Sturon), supplied by Greens of Soham, were planted on 19 July 2012 with three sets per rhizotron subsequently thinned to two per rhizotron after 10 days.

6.2.3. Recordings

The soil moisture was measured using a Field Scout TDR100 twice a week (Tuesday and Thursday) at the surface and two depths using access holes in the side of the rhizotrons at 35 and 70 cm depth.

Root distribution was assessed once a week on Wednesday. A 40 mm by 40 mm grid was drawn on an acetate sheet. The sheet was placed on to the Perspex cover and each cell with a root (either primary or secondary) was counted. The two grid squares where each set was planted were not included. The total cells containing one or more roots at each depth were counted. The rooting depth was split into Top (0-16 cm), Middle (20-44 cm) and Bottom (52-76 cm) rooting zones for analysis.

Thirty six days after planting the onion top growth was removed and weighed. The larger roots were removed and placed in cups, the remaining soil and fibrous rooting system was passed through the 5mm sieve. This allowed the soil to pass through but the rooting system remained to be gathered from the sieve surface. The onions, leaves and roots were bagged and placed in a drying oven for 24 hours at 80°C, and weighed for dry matter. The ratio of root dry weight to shoot dry weight was calculated as (Root DW/Shoot DW).

6.2.4. Statistics

All plant measurements were analysed by ANOVA using Genstat 13th Edition.

6.3. Results

The 2012 season was unusually cool and cloudy with reduced light levels as a consequence. There was no significant pest or disease damage to the crop.

6.3.1. Soil moisture

The moderate treatments were increasingly dryer than the wet treatments at the middle zone of the rhizotron but soil moisture did not differ significantly between treatments either at the middle or bottom zone of the rhizotron (Figure 6.1). The substrate was wetter at the bottom of the rhizotron with an average moisture content of 45% at the bottom of the rhizotron compared to 15% in the middle of the rhizotron.

6.3.2. Root Distribution Analysis

The most roots were observed in the top zone (average of 42 cells with roots) of the rhizotron, with fewer cells having roots visible in the middle (average of 27 cells containing roots) and bottom zones (average of 4 cells containing roots). There was no significant difference in the number of cells with roots between irrigation treatments (Figure 6.2).

6.3.3. Fresh weight

By the end of the experiment the onions grown with the wet treatment had a greater fresh weight of both root and top growth but the difference was not significant (Table 6.1).

6.3.4. Dry weight

As with fresh weight, the onions grown with the wet treatment had a greater dry weight of both root and top growth. The difference was significant (p=0.018) for shoot growth (i.e. leaves and bulb) with the wet treatment producing 10.80 g compared to 7.63 g for the moderate treatment (Table 6.1).

6.3.5. Root : Shoot analysis

The moderate treatments had a greater proportion of total biomass accounted for by root growth with a root:shoot ratio of 0.70 compared to 0.55 for the wet treatments, but this difference was not significant (Table 6.1).

	Fresh Weight (g/rhizotron)		**Dry Weight (g/rhizotron)**		
	Shoot	Root	Shoot	Root	Root:Shoot
Wet	18.06	7.07	10.80	5.97	0.55
Moderate	16.27	6.98	7.63	5.32	0.70
Mean	17.17	7.03	9.22	5.64	0.63
SE (n=6)	1.47	0.33	1.12	0.39	0.08
p	0.250	0.787	0.018	0.127	0.196

Table 6.1. *Fresh weight and dry weight biomass for root and shoot components at the end of the experiment.*

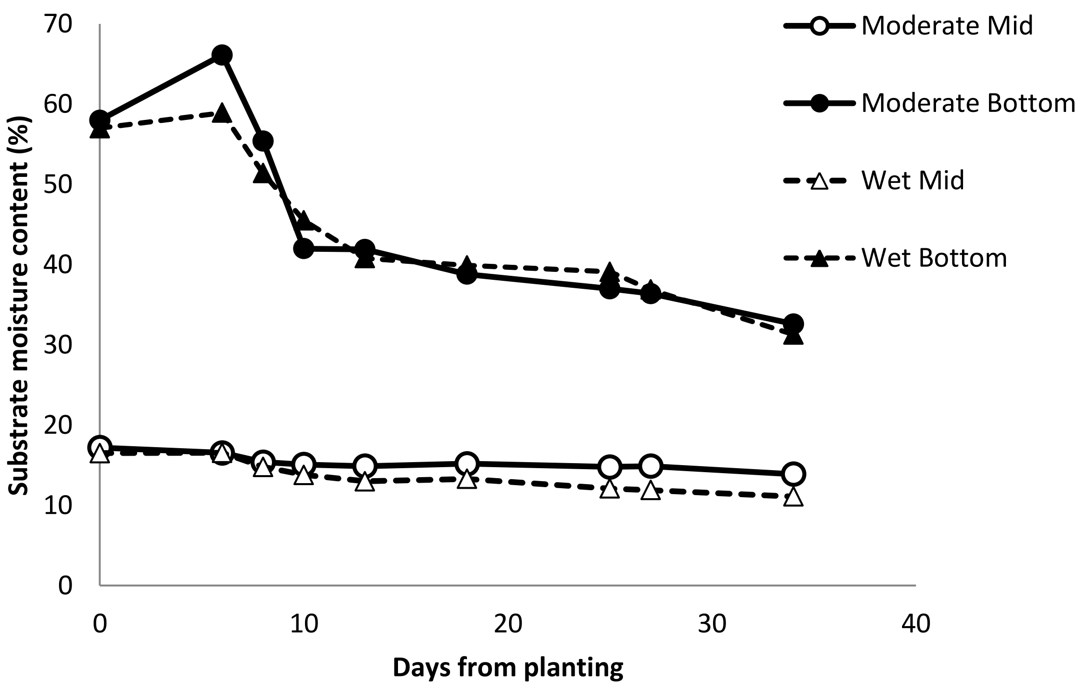

Figure 6.1. *Substrate moisture content at two depths over time. Moderate treatments received no water after day 18.*

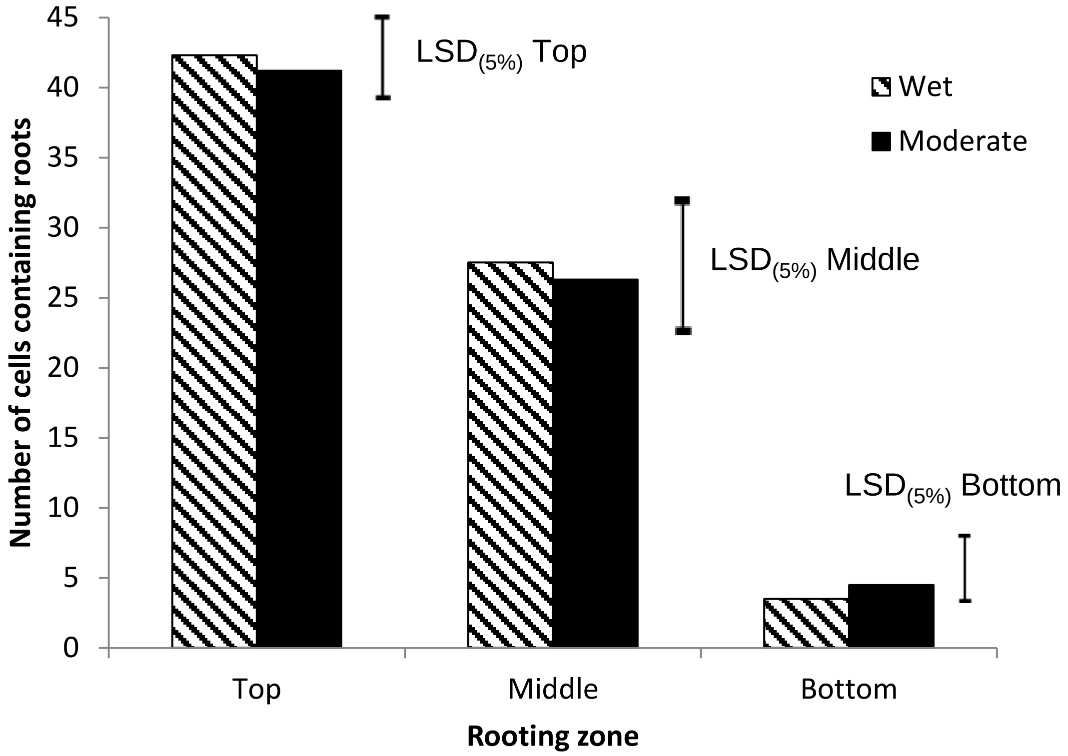

Figure 6.2. *Root distribution through the rhizotron at the end of the experiment*

6.4. Discussion

Does irrigation regime affect the rooting pattern of onion sets?

This experiment was unable to establish the effect of irrigation on the rooting of onion sets as it was not possible to generate significantly different treatments over the 36 days of the experiment. The water use by onions was low compared to other crops studied using rhizotrons such as lettuce.

Differences in soil moisture were starting to develop by the end of the experiment and leaf and onion growth was reduced in the moderate treatments suggesting that further work, extending the growth period may be needed to examine the response of onions to deficit irrigation.

6.5. Conclusions

- Onion sets do not root deeply in the first 5 weeks of growth
- Onion sets do not start to use significant amounts of water in the first 36 days after planting.
- Deficit irrigation treatments cannot be imposed early in the growth of onion sets

6.6. References

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