Improving greenhouse systems and production practices (greenhouse production practices component) (Parent - VG07096)

Barbara Hall
South Australia Research & Development Institute (SARDI)

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Level 7
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Telephone: (02) 8295 2300
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FINAL REPORT

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Dr Kaye Ferguson et. al.

South Australian Research and Development Institute

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Research Organisation: South Australian Research and Development Institute
GPO Box 397 Adelaide SA 5001

Project Leader: Kaye Ferguson
phone: (08) 8303 9627
email: kaye.ferguson@sa.gov.au

Key Personnel: Barbara Hall (Chief Investigator)
Jeremy Badgery-Parker
Keith Webb
Tony Burfield
Domenic Cavallaro
Sophie Parks

This report outlines the development of a manual to assist growers currently in low to medium technology soil based production systems to change to a hydroponic production system within their current infrastructure.

This project has been funded by HAL using the Vegetable Industry levy and matched funds from the Australian Government.

Note: This project is closely linked with HAL project VG08064 'Developing demonstration sites for simple hydroponics in protected cropping'. The information provided must be interpreted in conjunction with the final report for VG08064 completed in July 2011.

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1. Media Summary

In soil-based production systems poor soil health, soilborne diseases, soil salinity and increasing pressures on production are severely restricting productivity for many growers. In addition, vegetable growing regions are progressively being forced to the margins of arable land or onto non-arable land due to urban sprawl.

Hydroponic systems can eliminate many of the problems associated with soil-based production systems and when managed effectively can significantly improve productivity. However many growers are reluctant to move into hydroponics due to set up costs, high technological input, and the lack of expertise available.

Following consultation with many industry partners, the project has produced a best practice manual for conversion to simple hydroponics. Aimed at existing protected cropping growers interested in converting from soil-based production to hydroponics, it will also have application for growers looking to upgrade hydroponic systems.

Demonstration sites were set up both within this project and under an adjunct project (VG08064) to develop and prove some of the concepts, provide information to growers via field days, and to develop a companion DVD illustrating issues outlined in the manual.

Although the manual does cover basic management of hydroponic systems it is not designed to be another text on how to do hydroponics, but looks at the choices and decisions that need to be made before hydroponics is undertaken. It highlights the importance of having an overall plan for converting to hydroponics and how a step by step approach to conversion can make the process manageable and less risky.

The manual aims to assist the grower to examine their reasons for converting to hydroponics, explains the basics of hydroponic systems and management, emphasises what hydroponic systems can and cannot do for a grower's business, highlights the importance of having an overall plan and outlines the steps in conversion. The manual also ensures growers are well informed of the disadvantages as well as the advantages of hydroponics and correct many of the misconceptions about the capabilities of hydroponic systems. The manual will also help growers put together a good financial plan projecting the time to get a return on investment in hydroponic technology.

It is anticipated the manual will be ready for distribution by May 2012. When the manual is ready for distribution it will be advertised via several industry publications including Practical Hydroponics and Greenhouses, Soilless Australia and The SA Grower. Other state based industry publications will also be notified. A database of interested growers was compiled during the course of the project.

2. Technical summary

Development of the best practice manual for conversion to simple hydroponics was initiated by compiling information from many sources to determine what growers would need to know to manage the conversion. Information was sourced from:

- scientific and industry publications
- case studies of growers with hydroponic systems
- growers interested in converting to a hydroponic system
- researchers, consultants and industry personnel
- conferences and study tours in Australia and overseas.

Demonstration sites for conversion to hydroponics were set up in this project and in an adjunct project (VG08064) and crop data comparing yields and productivity in hydroponic and soil-based production systems collected. A DVD was produced as a companion to the manual, using the demonstration sites to illustrate some of the issues discussed.

In 2010 a block of eight glasshouses on the Northern Adelaide Plains was set up as a demonstration site within this project. Two complete cucumber crops were grown, with the third in progress at the time of writing. Outcomes from the site were:

- first crop planted January 2011 yielded 1.1 boxes/m^2
- second crop planted August 2011 yielded 1.3 boxes/m^2
- third crop planted January 2012 yielded ten times as many boxes in the first pick as the first crop
- grower's understanding of how to manage the system improved with each crop
- water use efficiency was significantly higher compared to soil grown crops
- anticipated return on investment within six years.

Grower days were held at the demonstration site throughout the project. Attendees were able to walk through the site, learn how the conversion was undertaken, view the equipment used, the crops being grown and learn about the capture, treatment and re-use of run-off water. Yields achieved since converting to hydroponics, water use efficiency and the projected return on investment were also discussed.

Communications with current and prospective hydroponic growers, researchers, consultants and industry personnel highlighted a number of important points which the manual addresses, including:

- the need to have realistic expectations of yields achievable in low technology greenhouses
- the importance of understanding which limiting factors in a production system a hydroponic system can address and which it cannot
- the time and crop management skill needed to manage a hydroponic system
- the importance of good quality water in hydroponics
- the key factors to a successful transition to hydroponics.

The best practice manual and DVD produced in this project will help growers:

- examine why they want to convert to hydroponics
- understand the basics of hydroponic systems and management
- understand what a hydroponic system can and cannot do for their business
- think about an overall plan for improving their production systems

- convert to hydroponics
- manage a hydroponic system.

It is anticipated the manual will be ready for distribution by May 2012.

3. Technical report

3.1 Introduction

The greenhouse industry is the fastest growing food producing sector in Australia with a farm-gate value of $600 million – 20% of the total value of Australia's vegetable and flower production[1]. Of the approximately 1600 protected cropping growers nationally, approximately 95% are growing in low to medium technology structures[2]. The largest number of small farms is located in New South Wales and South Australia. In South Australia the protected cropping industry mainly consists of small farms in soil based production systems. New South Wales is also mostly small farms but the majority are using basic hydroponic systems. Technology in other states is more evenly spread between low and high technology farms with fewer farms overall. Low technology soil based production is still occurring in Western Australia, Queensland, the Northern Territory, Victoria and Tasmania.

The majority of the protected cropping industry is not optimising productivity, either due to problems with soil or the low technology level of their structures, or a combination of both. Increasing the productivity of the industry was identified as a strategic imperative in the Australian Vegetable Protected Cropping Industry Strategic Plant in January 2007. Two projects arose from that need – the current project to improve productivity by helping growers convert to hydroponic production systems, and the partner project VG07145 'Improving greenhouse systems and production practices (greenhouse systems component)' that examined the impact of improved technology on productivity.

In soil based production systems poor soil health, soilborne diseases, soil salinity and increasing pressures on production are severely restricting productivity. In addition vegetable growing regions are progressively being forced to the margins of arable land or onto non-arable land due to urban sprawl. These factors have major implications for the sustainability of the protected cropping industry in Australia.

Soil fumigation is often the only option to control soilborne pathogens like nematodes and soilborne fungi but is often ineffective, particularly in the Northern Adelaide Plains in South Australia where the clay soils have a high sodium content and low permeability. High soil salinity and poor soil health are also major problems for many growers in soil production and increased pressures on production mean growers have little chance to remediate the soil. Often high soil salinity is a result of saline irrigation water and even though higher quality water would lead to higher productivity, growers find it difficult to justify expensive water treatment methods when productivity is already so low. For some growers, yields and quality may not be in decline, but ever increasing input costs mean they need to consistently increase yield and quality to improve productivity and remain viable.

Hydroponic systems address many of the issues with soil production, removing the need for fumigation and when managed effectively can significantly improve production and permit production on marginal or non-arable land. However there is reluctance on the growers' part to move into hydroponics through concerns with prohibitive set up costs, high technological input, and the lack of expertise available. However some growers have set up simple, inexpensive and economical systems in

[1] Australian Vegetable Protected Cropping Industry Strategic Plan 2006-2020, January 2007
[2] Australian Vegetable Protected Cropping Industry Strategic Plan 2006-2020, January 2007

their existing structures, sometimes initially with manual inputs. Steady increases in productivity in these simple conversions have enabled them to invest further in hydroponic technology.

This aim of this project was to improve the productivity of cropping systems used in Australia for greenhouse vegetable production by producing a best practice manual for conversion to simple hydroponics. For many growers, building new medium-high technology greenhouses that include a hydroponic system is prohibitively expensive, but converting to hydroponics in existing structures may be feasible. The best practice manual highlights the importance of having an overall plan for converting to hydroponics and how a step by step approach to conversion can make the process manageable and less risky.

The project has produced a best practice manual for conversion to simple hydroponics aimed at existing protected cropping growers interested in converting from soil to hydroponics. However it will also have application for growers looking to upgrade hydroponic systems.

3.2 Content development

To develop the best practice manual, multiple sources of information were consulted to better understand what growers would need to know to initiate and successfully complete the conversion.

3.2.1 Information sources

A literature search was undertaken of scientific and industry publications to source information for the best practice manual. In addition, information was sourced from growers with hydroponic systems, growers interested in converting to hydroponics, researchers, consultants and others working in the industry. Conferences and study tours were also a source of information.

Scientific and industry publications

Many publications were consulted when seeking information for the best practice manual. These included textbooks on hydroponics, industry publications such as Practical Hydroponics and Greenhouse magazine, training manuals for hydroponic production, research project reports, greenhouse production manuals, conference proceedings and industry websites. A full list of the sources from which information was included is in available in the bibliography of the best practice manual.

Although there was information available on setting up or managing a hydroponic system, much of it was aimed at growers starting from scratch with little information available to help growers wishing to convert existing greenhouses. The literature also suggested that growers needed to have one or more good reasons to convert to hydroponics and understand what hydroponics is and is not capable of achieving in their system. The importance of having realistic expectations about yields and productivity and the daily monitoring required in a hydroponic system was also highlighted by some publications. The importance of these points was reinforced during discussions with growers interested in converting to hydroponics (see below).

Researchers and industry personnel

Dr Kaye Ferguson collaborated with researchers in the protected cropping industry, in particular Mr Jeremy Badgery-Parker who is co-author of the best practice manual, and Dr Sophie Parks, both from NSW Department of Primary Industries. Information was also obtained during discussions with consultants, seed company and chemical company representatives, suppliers and re-sellers in the protected cropping industry. Through these sources information was obtained on management of hydroponic systems, pitfalls and traps, benchmarking and economic analyses.

Case studies of growers with hydroponic systems

Case studies of hydroponic production systems were conducted during farm visits with cucumber and tomato growers in New South Wales and South Australia and tomato and capsicum growers in Almeria, Spain. Almeria has very similar conditions to South Australia, with low technology greenhouses and hot summers.

New South Wales

<u>Grower 1</u>

Previously grew cucumbers, tomatoes and eggplants in soil. Growing cucumbers and tomatoes in hydroponics in blocks of plastic (poly) houses up to 3.5 metres to the gutter.

Water supply was mains water with an Electrical Conductivity (EC) of approximately 1mS/cm. Irrigation was automated via a Netafim® system using injectors and timing was based on a light accrued measured with a radiation sensor. Plastic shuttles (1000L) were used as A and B tanks to store concentrated nutrient solutions and the same nutrient mix was used for cucumbers and tomatoes. Measurements of EC, pH and run-off were taken every second day but were not recorded. The grower aimed for a feed EC of 2.4 mS/cm for cucumbers and 3.1 mS/cm for tomatoes with run-off percentage of 10-20% in winter and 30-50% in summer. The hydroponic system was run to waste with the run-off used to irrigate stock feed on their neighbour's property.

The growing media was cocopeat in Galuku easyfil® planter bags. The bags were delivered pre-filled as blocks, with holes pre-cut for drainage. Two cucumbers or two tomatoes were planted in each bag. Bags were reused 2-3 times and the grower noted that 3 crops was the maximum as the quality of the media declines with each crop, which reduced yield somewhat, but not enough to justify single use only. When finished with the bags the grower spread the contents under trees on the property. The grower has tried many different types of growing media including sawdust and potting mix and is happiest with cocopeat. The cocopeat has good water holding capacity and they find it easy to manage. Several different types of systems are used to support growing media and as gutters to capture and direct run-off from irrigation. In one system wires are stretched between metal supports to hold growing media above gutters sitting on the ground below that are made from plastic sheeting. In another system the growing media sits directly on the plastic sheeting gutters (Figure 1).

Pipe heating was used in some of their greenhouses, all greenhouses had passive ventilation. The newest house had misters but no stirring fans. Temperature, relative humidity and light were monitored via a sensor linked to a computer in the newest greenhouse.

Important points:

- Experimented with growing media and found that cocopeat easiest to manage in their system

- Misters without stirring fans can cause problems with humidity build up, leading to fungal diseases

Figure 1 Growing media support systems and plastic sheeting used for gutters at Grower 1 in Sydney Basin, New South Wales

<u>Grower 2</u>

This grower had always grown hydroponically and grows cucumbers and tomatoes. His greenhouses were plastic (poly), some in single tunnels as well as a large block of houses together.

Water supply is mains water with an EC of approximately 1 mS/cm and a pH of approximately 7.8. The high pH of the water means the grower has to add a lot of acid to bring the pH down. The hydroponic system was run to waste, with run-off going into a dam and from there it was used by his neighbour to irrigate fodder for stock. Concentrated stock solutions of nutrients were stored in metal tanks (1000L) and a different mix is used for cucumbers and tomatoes. Feed EC for cucumbers is 1.5mS/cm initially and is raised to 2.4mS/cm when fruiting. The pH is maintained around 5.9-6.2.

The growing media was potting mix in plastic grow bags with 2 plants/bag. The grower has tried many different media and his supplier now mixes a potting mix especially for him. He found cocopeat too wet in winter, particularly in cucumbers which are sensitive to waterlogging, so he formulated a growing media mix that he uses for cucumbers and tomatoes all year round. The potting mix contains ash, river sand and bark and has good balance between water holding capacity and drainage that he can use for summer and winter crops. The grower finds the potting mix cheaper and easier to manage than cocopeat. The media is reused 2-3 times and the grower notices slight yield losses with each subsequent crop but feels it is still better than replacing the media each year. When he is finished using the media he spreads it at the back of his property. Run-off is not measured daily but when he does measure it is recorded. The growing media is supported on plastic crates with a gutter made from plastic sheeting used to collect and direct run-off (Figure 2).

Pipe heating was used in winter. Temperature and relative humidity is monitored via sensors linked to a computer.

Important points:

- Experimented with growing media and tailored a potting mix that suits his requirements
- Metal tanks not recommended for irrigation systems as can react with nutrient solutions

Figure 2 Growing media support and gutter system (left) and greenhouse type (right) at Grower 2 in Sydney Basin, New South Wales

South Australia

Grower 1

This grower grew cucumbers, capsicum and tomatoes in soil for 20 years. At the time of the visit he had been growing hydroponically for 18 months and had converted to hydroponics because of problems with soil diseases. He was growing cucumbers and tomatoes in glasshouses approximately 1.8 metres to the gutter.

He catches rain water from the greenhouse roofs which is stored in a dam on the property and also has access to bore water with an EC of 1.6 mS/cm. He mixes his water supplies to lower the EC and make his rain water go further. The system is run to waste with run-off water going into ditches alongside greenhouses. Water samples were sent to a laboratory in The Netherlands to get a nutrient recipe. Concentrated nutrient solutions are stored in 1000L plastic shuttles and irrigation is automated via a fertigation unit with mixing tank and a Priva Maximiser supplied by Powerplants Australia. Paint stirrers are set above tanks to agitate the nutrient mixes. The grower has two A tanks and two B tanks so that he can irrigate crops of different types and different ages with different nutrient mixes. Irrigation scheduling is based on radiation accrued but the grower adjusted it manually when necessary. A monitoring station is set up in each block of greenhouses where EC and pH, and run-off are checked and recorded once or twice a day. Run-off is usually maintained around 20-30%. The grower aims to keep the EC in the run-off between 2.3 and 3.5 mS/cm and the pH around 5.7-6.5.

Cocopeat slabs are used as growing media and are supported by metal gutters sitting on bricks because the greenhouse is not high enough or strong enough to support hanging gutters (Figure 3). Four plants are planted in each slab. The grower has tried rockwool also and has found that rockwool was more suited to winter and cocopeat more suited to summer, due to the high water holding capacity. The slabs are reused at least twice, rotating cucumber and tomato crops.

There was no heating and only passive ventilation via doors.

Since converting to hydroponics yields had improved 20-30% and the grower had seen major improvements in the quality of produce. The plants grow much quicker than in soil which means he has to have the labour to keep up with them. A major advantage of hydroponics is there is no downtime associated with soil fumigation or rotary hoeing. The grower expected to get a return on his investment in hydroponics within two years.

Important points:

- Minimum daily monitoring of run-off from hydroponic system
- Had not found a media to use all year round, potentially needed to adjust irrigation strategies in winter to prevent waterlogging


Figure 3 Metal gutters on brick supports (left) and greenhouse type (right) at Grower 1 on Northern Adelaide Plains, South Australia

<u>Grower 2</u>

The grower grew tomatoes for seven years in the soil before converting some greenhouses to hydroponics. At the time of the visit he was growing his second crop of hydroponic tomatoes. He converted to hydroponics for a new challenge and maintained some greenhouses in soil production because it was what his market dictated. He had both glass and plastic greenhouse, 1.6 metres to the gutter.

His water supplies were rain water and bore water with an EC of 2.5 mS/cm. He mixed his water supplies so that the bore water was more suitable but the EC was still very high and prevented him from being able to grow cucumbers. Concentrated nutrient solutions were stored in 1000L plastic shuttles and agitated with large sticks by hand. He had obtained a nutrient recipe from his consultant. Irrigation was automated via a Netafim® fertigation unit. Irrigation scheduling was based on radiation accrued but the grower adjusted it manually when necessary.

The EC of his feed solution was 3.3–3.7 mS/cm and run-off EC around 3–4 mS/cm. pH in the feed and the run-off solution was 5.5–6.2. He was maintaining a run-off around 25–40% in summer and 10–15% in winter. High run-off % were needed in summer because of the high EC of his water supply and to manage blossom end rot. He took daily measurements on EC, pH and run-off and recorded them in a book. The system was run to waste with run-off being captured and stored then diluted to irrigate soil crops.

The grower used cocopeat slabs as a growing media and at the time of the visit was experiencing problems with a cheap brand of slab which had a high bark content that was not holding water well enough. In the previous crop he had more a reputable brand of cocopeat slab and had better control of water content in the slab. The grower had two types of gutters for supporting plants and capturing irrigation run-off – some pre fabricated plastic gutters and some metal, both were supported by metal brackets (Figure 4). He preferred the metal gutters as they were easier to work with and supported his plants better and intended to use metal gutters in any future conversions.

The grower sold his hydroponic tomatoes as truss so that required truss pruning, whereas his soil crops did not need as much pruning. His hydroponic crops had less plants per square metre than soil crops but yields were four times higher. Cherry and Roma tomato varieties had more flavour in hydroponics than in soil. In the future the grower wanted to install pipe heating

Important points:

- Higher yields in hydroponics with less plants per square metre

Figure 4 Metal gutters (left) and plastic gutters (right) at Grower 2 on Northern Adelaide Plains, South Australia

- Quality of some varieties higher in hydroponics

Grower 3

The grower at this property grew in the soil for four years before soilborne diseases, nematodes and high soil salinity forced him to convert to hydroponics. He was one of the first in the region to convert to simple hydroponics in low technology greenhouses and grows only cucumbers. He had 3 blocks of plastic houses, approximately 2.5 metres to the gutter.

His water supply is mains water and rain water collected from greenhouse roofs and stored in a dam. Rain water is used predominantly because the grower found rain water easier to manage in the system than mains water. When rain water supplies are low it is mixed with mains water.

A water sample was sent to The Netherlands to obtain a nutrient recipe for cucumbers. A starter mix is used initially and then a different mix when plants begin fruiting. Concentrated nutrient solutions are stored in plastic shuttles (1000L) and agitated manual with a large stick. That volume of nutrient solution lasts him approximately 15 days over winter. The grower tries to maintain an EC of 2.9 mS/cm in the feed solution and 3.4 to 3.8 mS/cm in the run-off solution. The pH in the feed solution is maintained around 5.4 and in the run-off around 5.6 – 5.8. EC, pH and run-off is measured at least twice daily, if it is hot then sometimes it is done after each irrigation. Like many new growers the grower had some teething issues in the first few years of hydroponic production and his diligent record keeping made it considerably easier for he and his consultant to find and correct trends and keep the system in balance.

For the first three years after converting to hydroponics the grower irrigated manually, which required him to be on the property all day every day whilst he had crops in. Yields improved by 50% in hydroponics compared to previous soil crops and within three years the grower was able to invest in a fertigation unit and controller from Galcon®.

The grower improvised a gutter system to support growing media and collect run-off using corrugated polycarbonate plastic sheeting and sloped the greenhouse floor to ensure run-off would drain to the collection point (Figure 5). Run-off from irrigation goes into a tank which is then used to water olive trees on the property.

Figure 5 Gutter system (left) and monitoring station (right) at Grower 3 on Northern Adelaide Plains, South Australia

The grower initially used potting mix in grow bags as a growing media but via a friend he had the opportunity to trial cocopeat slabs that had been used for one crop of tomatoes. Even with the used slabs he found the cocopeat more water use efficient due to the better water holding capacity – the water didn't run through the bags like it used to with the potting mix. He also lost less water to evaporation because the slabs were enclosed. He now uses cocopeat slabs and plants 4 cucumbers per slab. The cocopeat slabs used are up to three times, depending on disease issues in the previous crop. Old slabs are given to a friend who incorporates them into the soil.

Plants grew quicker in hydroponics than in soil and he weeded less because the soil surface was covered with plastic. There was no downtime between crops as fumigation or rotary hoeing was not required.

Important points:

- Less plants per square metre in hydroponics, but 50% higher yields
- No longer needs to plant all his blocks of greenhouses – doing more with less
- Run-off monitoring and record keeping is key priority

<u>Grower 4</u>

This grower grew tomatoes in the soil for approximately 20 years before converting to hydroponics due to soilborne diseases and the need to improve yield. He now grows tomatoes in a hydroponic system. His plastic houses are in two blocks, approximately 3 metres to the gutter. Water supplies are mains and rain water and are mixed together when required.

Concentrated nutrient solutions were stored in second hand 2000L tanks (Figure 6). Initially he started with 1000L tanks but found that in summer he had to refill the tanks every 3 days. Irrigation was done with a fertigation unit with mixing tank and Priva Maximiser from Powerplants Australia. Irrigation scheduling was based on radiation. The grower tries to maintain an EC in the feed of 2.8 mS/cm and in the run-off of 3.5–3.6 mS/cm. The pH is in the feed is generally 6 and in the run-off 5.7–5.9. The system is run to waste and the run-off is captured and used to water trees. Monitoring of EC, pH and run-off is done at least daily but is not recorded.

The growing media was cocopeat slabs which the grower had chosen due to the good water holding capacity and the price – cheaper than rockwool. However he had found issues with supply and consistency of cocopeat slabs and found that cheaper slabs did not pay off in the end. He had one cheap batch in which almost half the slabs did not expand properly when filling them before planting. He tried reusing slabs for a second crop but had noticed a significant yield reduction in the second crop. Old slabs were incorporated into the soil on his property or on friend's properties.

Pipe and rail heating had been installed but had not been used due to delays with accessing mains gas (Figure 6). He believed that hydroponics is better for him because the crops are longer term and the market is more stable for hydroponic produce. Tomatoes, as a higher value crop provided the best return on investment for him. In the future he would like to recirculate his water to improve water and fertiliser use efficiency.

Important points:

- cheaper cocopeat slabs not worth the reduced cost - consistency problems ended up costing him more in the long run
- had an overall plan to improve water and nutrient use efficiency by recycling run-off water


Figure 6 Gutter and heating system (left) and nutrient solution tank (right) at Grower 4 on Northern Adelaide Plains, South Australia

Almeria, Spain

Grower 1
The greenhouse on this property was 12000m^2 and was an example of a typical greenhouse in the Almeria region. Compost was laid on top of the natural soil and then 15-20mm of coarse 'sand' (gravel) sourced from a quarry was laid over the top to create a growing media for hydroponics (see Figure 7). The grower prefers to have the gravel on top of the natural soil because it acts as mulch, decreasing evaporation during summer and retaining heat during winter and also reducing weeds and soil diseases.

Rainfall was captured in the gutters on the greenhouse and stored in a tank on the property, in accordance with the local legislation. Rainfall was inadequate to meet crop water requirements so water was also sourced from a bore. The crop was irrigated with a hydroponic nutrient solution via an automated controller. Irrigation was initially every 3 – 4 days for around 30 minutes each time and the frequency of irrigations increases as the crop grows. The EC of the nutrient solution was approximately 1.3mS/cm and the pH around 6. The soil pH is 8 and the grower has had a lot of problems with calcium ions in the soil. The nutrient solution was mixed from five separate 1000L fertigation tanks, one each for calcium, potassium, phosphorous, one for ‘the others’, micronutrients included, and one for nitric acid that is used to control the pH.

The growing schedule on the property was typical of an Almerian greenhouse. Capsicum crops are planted at the end of July and grown through until February. A short crop of melon then follows and then the ‘soil’ is solarised from May to July, the European summer. The plastic used for solarisation is transparent and there is a 10cm overlap between sheets. During solarisation with all the vents closed and no chalk on the roof the ambient temperature inside the house can reach 60-70°C. After use the plastic is sent for recycling by local companies. The sand in the greenhouse has never been replaced. Capsicums are planted again at the end of July.

There was ventilation both in the roof and sides of the house and all vents were covered with mesh to exclude insects, particularly thrips. All vents had sticky traps to catch insect pests.

Important points:

- irrigation scheduling more similar to soil production than hydroponic production
- solarisation used over summer to control soil pathogens

Figure 7 Capsicum crop and gravel on top of soil at Grower 1, Almeria, Spain

Grower 2

This 12500m^2 greenhouse was located to the east of Almeria, which is traditionally a tomato growing area. The water quality in this region is not as good as the larger growing area southwest of Almeria. Tomato crops are grown in this region because they are more tolerant of salinity than cucurbit or capsicum crops. The area uses recycled mains water from Almeria. The EC of the raw water is 2mS/cm; with fertiliser added it is 2.5mS, with a pH of 7.4.

Three metres of sand had been brought in to level this greenhouse and the majority of the tomato crop was being grown using the sand as a media, in the system typical of the Almeria region (Figure 8). The grower stressed the importance of ensuring that sand that is brought in has the desired physical characteristics, like correct particle size and water holding capacity. Some of the sand that had been brought in was of poor quality and didn’t retain moisture as well as the other sand and so in those areas the grower was growing tomatoes in perlite slabs.

The crop was irrigated with a hydroponic nutrient solution mixed from five 1000L fertigation tanks. There was one tank for each of the calcium, potassium and phosphorous salts, one for everything else including the micronutrients, and one for the nitric acid used to control the pH of the solution. The perlite slabs were reused for up to 5 years providing there were no disease problems.

Planting density was 1.2 plants per square metre. The grower had experimented with planting densities and found that at lower density he could achieve the same yields with less problems, higher quality and lower costs. Yield in the previous year was 19kg/m^2 and the grower was aiming to have higher yields with even less fertiliser inputs in subsequent crops.

Important points:

- water quality dictated crop choice - raw water had high EC so grew tomatoes
- experimented with planting density and found lower planting density could achieve same yields as higher densities but with less disease problems, higher quality and lower input costs

Figure 8 Tomato crop in gravel (left) and perlite (right) at Grower 2, Almeria, Spain

Common outcomes from case studies

- Hydroponic crops produce higher yields with less plants per square metre than soil crops
- In many cases the run-off water from ‘run to waste’ system is not wasted but is reused somehow
- Growers are skilled at improvising infrastructure to support growing media and capture and direct run-off from irrigation
- Many growers were not keeping records and several were not doing daily monitoring of inputs and outputs of hydroponic system
- Lack of regular monitoring makes it difficult to detect trends and react quickly to problems and for growers or consultants to work out why things have gone wrong

- Lack of regularly monitoring of inputs and outputs monitoring means growers are not responding to crop's needs as quickly and accurately as possible and therefore not getting the best out of their investment in hydroponics
- Properties of growing media are key – need good balance between water holding capacity and drainage is critical as is altering irrigation scheduling to suit the age and type of crop and the climatic conditions
- Most cucumber growers use growing media for two or three crops, particularly cocopeat slabs – reductions in yield in second or third crops are acknowledged but do not justify new slabs
- Most tomato growers only use growing media once because it is a longer term and more high value crop

Growers interested in converting to hydroponics

Discussions were held in person, via email and on the phone with growers around Australia interested in converting to hydroponics to investigate the type of information they needed, their existing systems and their pre-conceptions about hydroponics.

Some growers found it very difficult to find suppliers who would supply for smaller properties and some found it difficult to find suppliers at all. Information on nutrient recipes and irrigation scheduling was also difficult to source and information on the benefits of add-ons to hydroponic systems like active ventilation or climate control. Several growers wanted to know if they could innovate parts of their system themselves instead of buying expensive off the shelf hydroponic equipment. Growers also wanted specific information on what sort of greenhouse floor covering to use, different types of gutter systems available and the advantages and disadvantages of different types of growing media.

Some growers had a complete misunderstanding of what hydroponics was capable of achieving. For example one grower said that he had to go into hydroponics because it was too hot to grow in the soil anymore. This is an example of a common misconception – that hydroponics controls the climate in the greenhouse. Some growers believed that hydroponics would give them 'complete control over the crop', another common misconception. Hydroponics and the associated add–ons, like climate control, can provide a higher level of control over the root zone of the crop but do not provide complete control. Good crop management is still the key as hydroponics does not grow the crop for a grower.

Other growers said that their soil salinity was too high and so they would have to go into hydroponics but many had not considered that if the source of their soil salinity was saline irrigation water, then that water source would also be a problem in hydroponics. Several growers had not calculated the volume of water they would need to run a hydroponic system.

Few growers had thought about the increased daily maintenance and monitoring required in a hydroponic crop compared to a soil crop. Also, the increased labour requirements were often not taken into account.

Many growers believed that investing in hydroponics was prohibitively expensive. Like any crop production system hydroponics requires a financial outlay. A good understanding of what can be achieved in hydroponics and a realistic financial projection are important and must be the basis of an overall plan.

Several growers had thought a few steps ahead and wanted to know what simple things they could do when setting up a hydroponic system that would substantially improve the functionality of the system and facilitate further improvements in technology.

The information gaps that identified by growers have been included in the best practice manual and misconceptions addressed to improve grower's understanding of how hydroponics can be used to improve productivity in their system and ensure growers make the transition to hydroponics with realistic expectations.

Demonstration sites

Three sites were set up to demonstrate conversion to hydroponics in different structures on commercial properties. One demonstration site was set up on a commercial property as part of this project. The other two demonstration sites were set up in the adjunct project VG08064 'Developing demonstration sites for simple hydroponics in protected cropping' – a summary of which is provided in the final report completed August 2011. Information on the process of conversion, equipment used at the different sites, problems encountered, things to watch out for and lessons learned was included in the manual and the companion DVD. Further information on the demonstration sites is included in a later section.

Conferences and study tours

Dr Kaye Ferguson attended the International Symposium for Soilless Culture and Hydroponics in Peru from August 25 to 28 2008. The conference brought together researchers, growers and industry personnel from around the world to report on simple hydroponic systems, growing media, plant nutrition and salinity, root diseases and water disinfection systems. The conference also included a tour of several commercial hydroponic properties around Lima and provided direct contact with growers who are successfully producing vegetables in greenhouses using simple hydroponic systems. Attendance at the conference provided the opportunity to meet with international experts in the hydroponics field and develop a network of contacts with researchers and consultants.

Following the conference, Dr Ferguson participated in a study tour of the protected cropping industry around Almeria, Spain. The Almeria region is comparable to many of the Australian greenhouse growing regions, particularly South Australia, in terms of the climate, the crops grown, property size, the pest and disease issues and the grower demographic. However growing systems and technology around Almeria, even though simple, are more advanced than the majority of those in Australia. This provided an invaluable opportunity to learn from the successes and failures of an industry that mirrors our own. The aim of the trip was to conduct case studies with commercial hydroponic vegetable growers and develop a network of contacts to help co-ordinate a study tour for growers and industry personnel. The trip to Almeria also included a visit to a research institute and provided the opportunity to meet with researchers in plant pathology and hydroponic technology. The conference and study tour details from the milestone report are included in the Appendix.

In 2010, as part of a separate project (VG09112 'Protected cropping grower tour, Europe'), and as a result of initial visits, Dr Kaye Ferguson returned to Almeria, Spain as joint leader of a study tour of protected cropping growers and industry personnel to visit properties using simple hydroponic systems. The trip was invaluable for growers and innovations seen and knowledge gained that has helped improve practices on their own properties.

3.2.2 Manual outline

Following the consultations with industry and grower participants, it was determined that the potential content of the manual should assist the reader to:

- examine why they want to convert to hydroponics
- understand the basics of hydroponic systems and management
- understand what a hydroponic system can and cannot do for their business
- think about an overall plan for improving their production systems
- convert to hydroponics
- manage a hydroponic system

There has been much interest from the protected cropping industry in the development of this manual. It aims to addresses knowledge gaps, ensure growers are well informed of the disadvantages as well as the advantages of hydroponics and correct the misconceptions about the capabilities of hydroponic systems.

The manual is not designed to be another text on how to do hydroponics, but takes a step back and looks at the choices and decisions that need to be made before hydroponics is undertaken. The manual puts a strong emphasis on the importance of having a well thought out, whole of farm and forward thinking plan and to have realistic expectations of what can be achieved in different situations. The manual will also help growers put together a good financial plan projecting the time to get a return on investment in hydroponic technology.

The manual includes the following:

1. How to use the manual and what growers can expect to get out of it
2. What is hydroponics and how it fits within a crop production system
3. Basic components of hydroponic systems – water, nutrients, irrigation infrastructure, suitable conditions, add-ons
4. Types of hydroponic systems – substrate, water, air and how systems are further defined as open, closed, recirculated or flow-through
5. Advantages of hydroponics
6. Drawback and limitations of hydroponics
7. How hydroponics differs from growing in soil
8. Reasons for converting to hydroponics – the good and the bad and whether hydroponics can achieve what growers need it to
9. Water requirements – quantity and quality
10. Nutritional requirements
11. Choosing a hydroponic system
12. Hydroponic substrates
13. Monitoring inputs and outputs
14. Budgeting and benefit-cost analysis of converting to hydroponics
15. The importance of an overall plan – the decision to integrate or overhaul
16. Basic management of hydroponic systems – nutrient recipes, daily monitoring, irrigation scheduling
17. Maintenance of hydroponic systems
18. Waste management
19. Demonstration sites for conversion to hydroponics – summary

20. General crop management – planting density, plant support, plant balance, benchmarking
21. Add-ons to a hydroponic system – climate control and monitoring, water disinfection
22. Other things to consider – do you have time to do hydroponics, what do you know, what can you learn, what support do you have available?
23. Key factors for success in hydroponics
24. FAQs/Troubleshooting
25. References
26. Acknowledgements
27. Detailed index

3.3 Demonstration sites

Three demonstration sites were set up on commercial properties demonstrating conversion from soil production to hydroponics. The sites were designed to provide practical examples of conversions and highlight the advantages and disadvantages of hydroponic production compared to soil production. Sites 1 & 2 were set up in an adjunct HAL project VG08064 'Developing demonstration systems for simple hydroponics in protected cropping'. A summary of the site details is included here. Site 3 was set up in this project using a different type of greenhouse structure and alternative gutter systems and growing media.

The main aims of the demonstration sites were:

- provide practical examples of how to convert to hydroponics
- demonstrate what to expect after conversion to hydroponics
- provide information for the best practice manual for conversion to simple hydroponics

3.3.1 Site 1 – Northern Adelaide Plains, South Australia

At a property on the Northern Adelaide Plains, South Australia yields of soil grown tomato and cucumber crops had been steadily declining for several years due to high salinity (high sodium and high chloride) levels in the soil. The primary water source at the property was a highly saline bore with an EC of 2.3mS/cm and irrigating with this water was increasing soil salinity and severely reducing productivity. Only a very limited amount of rain water was captured from greenhouse roofs due to limited storage capacity. Average yield in the soil for cucumbers was 0.7 bags/m^2 and for tomatoes was 5kg/ m^2. Cucumbers are highly sensitive to salinity and only short term (<3 months) low yielding crops could be grown at the site. The quality of tomatoes produced had been declining with more fruit of a lower grade being harvested.

The growers knew their lack of good quality water was a major problem. They considered reverse osmosis equipment but decided it was too expensive. So they decided to convert to hydroponics in two stages, initially accepting that even after converting to hydroponics, productivity would improve but would still be limited to an extent by their low quality water. In the first stage they converted two of their five blocks of greenhouses to hydroponics and irrigated with the existing bore water supply. After the first stage in the conversion to hydroponics yields of crops almost tripled to 14.6kg/m^2. However they knew that water quality was still a major limiting factor and they were not optimising their investment in hydroponics. They needed to get access to a raw water supply with a lower EC so they could shandy it with their bore water and be able to provide more nutrition to their crops.

In the second stage they established alternative water supplies by building a large dam to capture and store the rainwater from the greenhouse roofs and also installed sumps and water treatment equipment that enabled them to capture, treat and re-use their run-off water. This provided them with an alternative water supply that they could shandy with their bore water to reduce the salinity levels. Reusing run-off water increased their water and fertiliser use efficiency. With better quality water yields of tomato crops increased to $20kg/m^2$ and cucumber crops to $2.75kg/m^2$, four times the yields they were getting in their soil crops.

The growers knew that continuing to irrigate their soil crops with saline bore water was unsustainable. Yields weren't optimal after the Stage 1 of conversion to hydroponics but they were a huge improvement compared to yields of soil crops. Those improvements in productivity enabled them to reinvest in their farm in Stage 2 of the conversion and achieve further yield increases. Reusing run-off water has enabled them to save on their water and fertiliser costs which has contributed to improved productivity.

A full report of Site 1 is available from Ferguson (2011)[1]

3.3.2 Site 2 – Murray Bridge, South Australia

A small family operation growing a niche product in low technology greenhouses at Murray Bridge, South Australia wanted to optimise productivity in their limited greenhouse area. They also wanted to maintain continuity of supply without flooding the market with their product. Although their soils were still in reasonable condition they suspected they could be doing more with less. Their low technology greenhouses without climate control and limited production area limits planting of successive crops. So they converted some of their greenhouses from soil production to hydroponics.

After converting to hydroponics the growers saw improvements in yield and quality and a significant increase in the length of their harvest period. Hydroponic crops grow faster than soil crops and in hydroponics they start harvesting earlier and harvested for longer. The growers can now produce up to 30 trusses/plant in hydroponics compared to the maximum of 6 trusses they could produce in soil. In most cases their yields and returns tripled after converting to hydroponics.

Since converting to hydroponics the growers are able to supply their market continuously for 9-10 months of the year because they get their year's production out of a single planting in each greenhouse, rather than having to re-plant once or twice during the year. In hydroponics they now only plant three greenhouses. Previously to get the same return in soil production they had to plant 15 greenhouses and had significant downtime due to the need to replant crops.

Importantly, the growers understand their limitations. Being a small family operation they know that they do not have the labour to cope with planting more greenhouses in hydroponics as the daily maintenance would be beyond their capabilities. The growers

[1] Ferguson, K.L. (2011) Horticulture Australia Limited Final Report for VG08064 'Developing demonstration sites for simple hydroponic systems in protected cropping'

have optimised productivity for their labour force and their market is continually supplied but never flooded.

A full report of Site 2 is available from Ferguson (2011)[1]

3.3.3 Site 3 – Northern Adelaide Plains, South Australia

At this site the grower had been growing in soil in low technology greenhouses, less than 2 metres to the gutter and without climate control for 6 years. At the back of the property there was run down greenhouse of a similar height that had been used by the previous owner for many years to grow tomatoes. When the grower wanted to increase his production area and the productivity of his farm he decided to build a new greenhouse which included a hydroponic system. Glass and some other materials were salvaged from the old greenhouse on the property and used to build the new greenhouse. The total cost of the conversion is outlined in **Table 1**.

Infrastructure

Greenhouses

- One block of eight greenhouses, each greenhouse 33m long by 5m wide with a height of 3.1m to the gutter
- Both ends of block of greenhouses can be rolled up (roller sides) for ventilation and ends of roof section can be ventilated separately (Figure 9)
- Total production area approximately 1100m^2

Water sources

- Mains water
- Bore water with EC of approximately 1.3 mS/cm

Site preparation for conversion

The soil surface was rotary hoed to remove weeds, compacted and then laser levelled to create a fall of 300mm to the end of each row and 300mm to the corner of the greenhouse where the run-off collection point was located. Overall the slope was approximately 1%. Trenches were dug and primary pipe work 80mm in diameter was installed to deliver irrigation from the fertigation unit and to capture and direct run-off from irrigation. Secondary pipe work 19mm in diameter was installed from the primary pipework down the length each row. Trenches 500mm deep and 500mm wide were also dug down the rows of the greenhouse to install the system for collecting the run-off from irrigation. The trenches were lined with plastic, 50mm diameter agpipe was laid along the trenches which were then back-filled with a coarse compost (Figure 10). This created an in-ground gutter system for collecting run-off from irrigation based on a system seen when visiting Spanish growers.

[1] Ferguson, K.L. (2011) Horticulture Australia Limited Final Report for VG08064 'Developing demonstration sites for simple hydroponic systems in protected cropping'

The greenhouse roof was chalked before the next step to minimise the chalk contamination through the rest of the conversion process. Weed mat was laid and cut around pipe work and poles and anchored to the ground with weed mat anchors - plastic spikes with a large flat head to hold weed mat in place.

Figure 9 Construction of new greenhouse (left) and completed greenhouse (right)

Drippers
Pressure compensating drippers with an output of 3L/hour were attached to the secondary irrigation lines. Sections of spaghetti tubing 500mm long were used to connect the drippers to stakes which were placed into the growing media, one per plant (Figure 10).

Figure 10 In-ground gutter system (left) and drippers and spaghetti tubing on secondary irrigation line (right)

Substrate
The grower chose to use cocopeat in pre-packaged slab as a substrate (Figure 11). Two different brands of cocopeat slabs were sourced and the grades and bark content matched as closely as possible to facilitate irrigation management. The slabs were pre-punched with five holes. Slabs with filled with the starter mix nutrient solution and five seedlings of Kenia, a green (slicer) cucumber variety were planted per slab.

 

Figure 11 Cocopeat slabs before being filled with nutrient mix (left) and monitoring station (right)

Monitoring station

A monitoring station was set up in the greenhouse using a metal gutter offcut slightly longer than a single slab that was sourced from another grower. The section of gutter was supported by bricks with a slight slope to one end at which PVC piping was attached to direct run-off from irrigation into a bucket. Another bucket was used to collect the output of an extra dripper (Figure 11).

Fertiliser tanks and nutrient mix

Two 1000L shuttles were used as fertiliser tanks, one 'A' tank and one 'B' tank (Figure 12). A nutrient recipe was sourced from the grower's seed company representative.

 

Figure 12 'A' and 'B' tanks of concentrated nutrient solution (left) and fertigation unit (right)

Fertigation machine and controller

The grower installed a Priva Nutrifit CHI20-30 HX fertiliser dosing system linked to a Priva Maximiser controller supplied by Powerplants Australia (Figure 12). The fertigation unit was interfaced with the grower's PC on which software was installed. The fertigation machine had a 250L mixing tank and venturis mix the desired EC and pH by injecting the concentrated nutrient solution into the raw water stream which is stored in the tank before commencing irrigation. The fertigation unit was capable of an output of 9.5 m^3/hour, sufficient for the current production area and would also allow for expansion in the future.

Daily monitoring
The volume of the solution collected from the extra dripper (the feed) and the volume of solution that drains out of the slab (the run-off) after irrigation is measured and recorded daily. As the run-off is from four plants the volume is divided by four to get the run-off per plant. This is then used to calculate the run-off percentage.

The EC and pH in the feed solution and the run-off solution were also measured with a hand-held meter and recorded. These measurements were used to check and adjust irrigation strategies to ensure conditions in the root zone remained favourable for the crop.

EC, pH and run-off targets
The grower maintains the EC in the feed solution around 3.0 mS/cm and aims to keep the EC of the run-off solution below 5.8. If the EC of the run-off goes higher than 5.8 the cucumber show evidence high salinity e.g. edge burn on leaves. pH is maintained at approximately 5.6. The run-off percentage is varied according to the climatic conditions. Generally it is approximately 30%, in hotter conditions it is increased to 40-50% to ensure that the EC in the slab does not increase to unfavourable levels.

Table 1 Infrastructure, equipment and upgrades for conversion to hydroponics at Site 3, 2009-2010

Equipment	**Details**	**Cost**	**Supplier**
Fertigation machine	Priva Nutrifit CHI20-30 HX and Priva Maximiser	$32,355	Powerplants Australia
Fertiliser tanks	Chemical shuttles x 2	Free	Local supplier
3 phase connection	Bring 3 phase electricity to fertigation shed	$6,280	Electrician
Irrigation equipment	Primary and secondary lines, drippers, spaghetti tubing	$8,669	Virginia Irrigation Star Drip irrigation
Trenching	For capturing and directing run-off, includes contractor and labour	$3,000	Contractor
Ag drain and plastic	For capturing run-off from irrigation	$1,818	Local supplier
Compost and spreading	For spreading inside trenches	$2,465	Jeffries Peats Soils
Weed mat	White woven material, includes weed mat anchors and labour to install	$2,680	Local supplier
Tank	Store run-off from irrigation	$2,555	Local supplier
Seed	Grower raised own seedlings in nursery greenhouse on property	$960	Partially supplied gratis by Rijk Zwaan
Total		**$60,782**	

Yields

First crop (2011)
In the first crop the grower raised his own seedlings in speedling trays. Despite the numerous technical issues described earlier he achieved a reasonable return from the crop (Figure 13).

Transplanted:	3 January 2011
Picking commenced:	16 February 2011
Time from transplanting to picking:	47 days
Number of boxes in first pick:	8
Final picking date:	20 April 2011
Total yield:	1240 boxes
Picking period:	64 days
Average yield:	1.1 boxes[1]/m^2
Return:	\$18.7[2]/m^2

Figure 13 First crop at the site three weeks after planting (left), the grower attaching to support strings using plastic clips (middle) and alternative attachment of support strings to seedlings by tying (right)

Second crop (2011)
In the second crop the grower raised his own seedlings in rockwool cubes (Figure 14) which meant a significantly more advanced seedling was transplanted than when using speedlings. Yields and productivity in the second crop increased compared to the first crop and the harvest period was extended.

Transplanted:	13 August 2011
Picking commenced:	2 Oct 2011
Time from transplanting to picking:	48 days
Final picking date:	21 December 2011
Total yield:	1444 boxes
Picking period:	82 days
Average yield:	1.3 boxes[3]/m^2
Return:	\$22/m^2

[1] A box contains 28 to 32 green cucumbers, depending on fruit size, average weight is 14kg
[2] Based on average price per box of \$17
[3] A box contains 28 to 32 green cucumbers, depending on fruit size, average weight is 14kg

Third crop (2012) – in progress

Even though picking had just commenced in the third crop at the time of writing, it was already evident that this crop was a major improvement on the first crop planted at the equivalent time the previous year. Picking commenced more than two weeks earlier and the first pick yielded more than ten times as many boxes than the first pick in the first crop. A lack of teething problems and significant improvements in the grower's understanding of the system has contributed to the steady improvement in productivity with each crop.

Transplanted:	7 January 2012
Picking commenced:	7 February 2012
Time from transplanting to picking:	30 days

Figure 14 Cucumber seedlings in rockwool cubes in nursery greenhouse (top left) and transplanted onto cocopeat slabs (top right) and the crop five weeks after transplanting (bottom)

Greenhouse climate

The temperature and relative humidity in the greenhouse was monitored using a Tinytag Plus 2 datalogger which records measurements every 10 minutes. The temperature in slabs on the ground and on the monitoring station was also compared using Tinytag Plus 2 dataloggers attached to probes which were inserted into slabs.

The greenhouse reached temperature extremes of up to 45°C in summer and below 10°C in winter. Relative humidity also fluctuated greatly, regularly reaching 100% and below 30%. The climate was still a dominant influence on crop production.

In the hotter months temperatures in the slab sitting on the ground generally maintained a more favourable temperature range over the day than the slab sitting in the metal gutter. Temperatures in the slab on the gutter often peaked 2-3°C higher, sometimes reaching over 30°C and dropped 2-3°C lower over the course of the day (Figure 15).

In the cooler months the overnight temperature in the slab on the metal gutter was generally 1-2°C higher than the slab on the ground. Day time peaks were slightly higher and slightly advanced compared to the slab on the ground (Figure 16).

These results indicate that metal gutters may have a slight advantage in maintaining higher root temperatures overnight during winter in unheated greenhouses, but in the summer months may be a disadvantage because root zone temperatures can get too high.

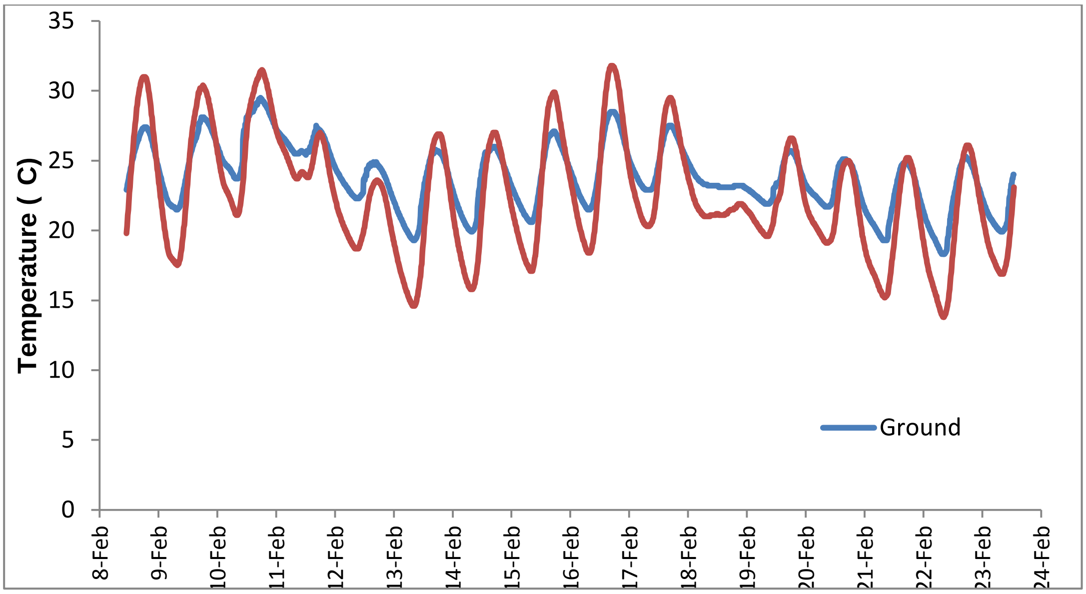

Figure 15 Temperature of cocopeat slab sitting on ground compared to cocopeat sitting in metal gutter in demonstration site greenhouse on Northern Adelaide Plains, South Australia in summer 2011

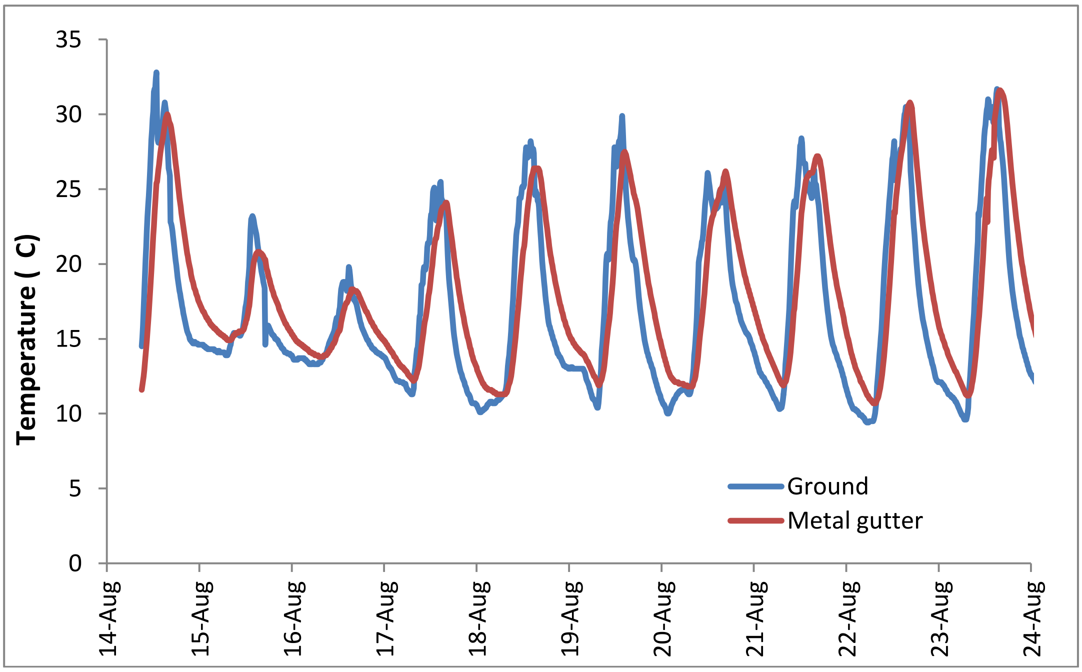

Figure 16 Temperature of cocopeat slab sitting on ground compared to cocopeat sitting in metal gutter in demonstration site greenhouse on Northern Adelaide Plains South Australia in winter 2011

Water use efficiency
Water use efficiency is significantly higher in the hydroponic system compared to previous soil grown cucumber crops. As an example, on a hot day the grower uses approximately 7,000 L/day to irrigate the cucumber crop in the hydroponic system. For equivalent cucumber crops in a soil based system over the same area he was using approximately 9,000 L/day. Not only is the grower already using less water on the hydroponic system, but he is also able to recover approximately 1,500 L (22%) of the water he uses and use it to irrigate his soil grown crops, after diluting with raw water (approximate ratio of run-off water to raw water 1:6).

Return on investment
The grower estimated that a return on investment in hydroponics in this system could be achieved within six years.

Problems
Converting to three phase power was an ongoing problem at the site with major delays with the state electricity distributor and private electricians that significantly delayed this project. To date the issues have still not been resolved and although not ideal and labour intensive, the grower is currently running the fertigation unit using a diesel generator. He hopes to have three phase power connected to the site by the middle of 2012 (more than two years after starting the process).

In the first few months after converting to hydroponics the grower experienced several problems that impacted on his ability to manage the crop. Initially there were issues with getting the grower's computer to interface with the fertigation unit. It turned out to be a problem with the USB port on the grower's laptop and was resolved when the laptop was replaced with a PC.

There was also a problem with pumps on the fertigation unit not maintaining the right pressure which meant the grower struggled to maintain a high enough run-off percentage. The problem was eventually traced to an installation issue and was resolved by the supplier.

Figure 17 First crop approximately five weeks after transplanting when grower had insufficient labour to keep up with pruning and training required (left) and approximately seven weeks after planting (right)

The unforseen demands of increased daily maintenance were also a problem in the first crop. The cucumber crop grew at a much more rapid rate than the grower anticipated and he was unable to keep up with pruning and twisting of plants in the early stages (Figure 17). The problem was resolved by hiring additional labour for crop maintenance and harvesting.

Summary

This site, as with the other demonstration sites set up in the adjunct project were not designed to be trouble-free conversions. They were designed to identify and document the normal teething issues and unforseen problems experienced by a grower making significant changes to their crop production system. Several critical lessons were learned during conversion to hydroponics and in the first two crops grown after the conversion.

The problems experienced in the initial crop have been greatly outweighed by the advantages of the hydroponic system. The grower has felt more comfortable with each crop he has planted as his knowledge of the hydroponic system and crop management has increased. Yields and productivity improved significantly in the second crop compared to the first and early indications from the third crop are that they will improve even further. There have been no problems with soil–borne diseases and cocopeat slabs are now being used for the third consecutive cucumber crop.

If fertigation equipment requires three phase power then ensure the power is connected before proceeding with the conversion. Delays in getting three phase power connected can be extremely costly. If three phase power is not available, then ensure fertigation equipment suppliers are aware of that and supply equipment that only requires single phase.

Growers should have realistic expectations of what they will be able to achieve with their first crop. Invariably there are problems with the fertigation equipment or issues with learning how to use the system to maintain the desired conditions in the root zone. Understanding how monitoring inputs and outputs can be used to quickly and accurately make adjustments to keep root zone conditions consistent is crucial to getting the best out of a hydroponic system. Unlike soil based production systems there is little buffer for plants if conditions are sub-optimal. It can take several crops for a grower to grasp the technical aspects of the system and provide optimal and consistent conditions in the root zone, particularly in climate extremes when in non-climate controlled greenhouses.

Growers should also be aware of the increased daily crop maintenance required in hydroponic crops. Initially the grower did not have sufficient labour to cope with increased labour requirements and learnt very quickly that hydroponics does not have the 'set and forget' aspect found in many soil production systems. Timely crop maintenance is critical.

Hydroponics has significantly decreased the turnaround time between crops. Crops can be pulled out and replanted within one to two days, including thorough sterilising of irrigation equipment. Also, because the grower raises seedlings in rockwool cubes, the time from transplanting to the start of harvest for each crop is significantly reduced compared to soil grown crops because a more advanced seedling is transplanted. That means less downtime between crops and a more continual supply of both fruit and cashflow. Transplant shock is also significantly reduced using rockwool cubes and there is potential to extend the harvest period by several weeks because healthier plants are grown.

Benchmarking of production parameters is extremely important so that a grower can monitor production in consecutive crops. Recording yields of saleable and unsaleable fruit, time to harvest, and the length of harvest period and comparing between crops can tell growers whether they are improving, staying the same or going backwards. Recording transplanting dates and the quantity of cucumbers picked on each date has allowed the grower to make direct comparisons between his first crop and his current crop, with significant improvements noted already. The cost of planting seeds into rockwool cubes is justified by significant labour savings for transplanting, the faster onset of harvest, higher yields, and the potential for extending the harvest period by several weeks.

Even though the project is now completed, the grower continues to allow access to the demonstration site for other growers interested in converting to hydroponics and provides an open and honest account of his experience to date. This ongoing access is an in-kind contribution by the grower to the sustainability of the greenhouse industry for which the project team are very thankful.

3.4 Reference group

A reference group of growers, consultants, industry personnel and researchers communicated regularly in person, via email and via phone to guide the content of the manual and the design and management of the demonstration site.

3.5 Production benchmarking parameters

During the project parameters were identified that could be used to identify and quantify the differences between crops. Parameters measured included:

- Time from transplanting to picking
- Total yield
- Average yield (boxes/m^2 or kg/plant or kg/m^2)
- Picking period
- Average number of trusses harvested/plant (for tomatoes only)
- Return ($/$m^2$)
- Stem growth (mm) – measured weekly (mainly used for tomatoes)
- Stem diameter at the head (mm) – measured weekly (mainly used for tomatoes)
- Water use (daily)

Where possible, these parameters were used to demonstrate the differences between crops grown in soil and crops grown in hydroponics at the demonstration sites. Further details can be obtained from Ferguson (2011). Recording crop growth data such is extremely valuable for growers when converting to hydroponics so they can identify whether yields and productivity have improved, stayed the same, or gotten worse. Comparisons can be made to soil grown crops and also to crops grown over the same period in previous years.

3.6 Testing and demonstration of draft best practice manual

The best practice manual has been regularly reviewed by the reference group to ensure that the content is relevant and current. Final reviews are underway and will be completed in March 2012.

The content and purpose of the best practice manual was also outlined at a presentation by Dr Kaye Ferguson at Protected Cropping Australia’s annual conference held in Adelaide in July 2011. Interest and comments were received after the presentation and via a booth manned by SARDI personnel throughout the conference.

The project to produce the manual has also been advertised in various industry publications and Dr Kaye Ferguson has received comments and suggestions from numerous growers throughout Australia.

It is anticipated the manual will be ready for distribution by May 2012. When the manual is ready for distribution it will be advertised via several industry publications including Practical Hydroponics and Greenhouses, Soilless Australia, The SA Grower. Other state based industry publications will also be notified. A database of interested growers was also compiled during the course of the project.

3.7 DVD production

A DVD was compiled during the project highlighting important aspects of converting to hydroponics and managing crops in a hydroponic system. Topics include site preparation, daily monitoring, calculating fertiliser inputs, capture and re-use of run-off water, benchmarking crop growth and the limitations of hydroponics in low technology greenhouses. Several sections of the DVD have been recorded in Vietnamese. The DVD will compliment the information provided in the manual by providing practical demonstrations of stages in conversion and crop management.

The DVD will be provided with the manual to assist growers with their conversion efforts.

3.8 Knowledge gaps

A number of knowledge gaps were identified throughout this project that are outlined in Table 2.

Table 2 Knowledge gaps identified during the project

Knowledge gap	**Has this project addressed? (Yes, somewhat or not within scope)**	**Comments**
Water use efficiency of production in hydroponic system compared to soil production system	Yes	Demonstration sites showed higher water use efficiency in hydroponic production system compared to soil base production systems.
Alternative support systems for growing media. Low-medium technology greenhouses are unable to support the hanging gutter systems used in high technology greenhouses. Many different simple systems possible.	Yes	Case studies with hydroponic growers outlined the design and pros and cons of various different support and gutter systems. Best practice manual describes desired features of gutter systems and what to consider when improvising systems.
Large variation in the quality and consistency of some growing media, particularly organic media like cocopeat. Many different suppliers importing cocopeat into Australia, none is produced locally and anecdotal evidence suggests 'you get what you pay for'. Quantifying the differences would enable growers to make more informed growing media choices.	Somewhat	Two brands of cocopeat were used at the demonstration site – one well-known brand and one from a supplier new to the market. No discernible difference in the yield or quality of fruit was detected which is likely due to both being high quality media despite one being less expensive. Best practice manual outlines desired characteristics of growing media. Further research comparing high quality with low quality, cheaper media is needed to demonstrate that anedoctal evidence is accurate.
Parameters for management of different media for different crops. Many growers who convert from soil growing to hydroponics continue to irrigate in the hydroponic media like they did in soil	Somewhat	The differences between irrigating in the soil and irrigating in hydroponic growing media are covered in the best practice manual. Research on infiltration rates of different growing media needed

Knowledge gap	**Has this project addressed? (Yes, no or somewhat)**	**Comments**
Effective and economical disinfection of water for low-medium technology greenhouses	Somewhat	Ultrafiltration disinfection system installed at Freshways demonstration site, effectively treating run-off water
Limitations in hydroponics with different water sources – mains, bore, rainwater, run-off, recycled. Is there a point where hydroponics is not viable with certain water sources?	Somewhat	The limitations of water sources with high salinity demonstrated at Freshways demonstration site. Improving water quality improved yield and productivity.
Management of run-off water from greenhouses. If legislation goes the way it has overseas and dictates that run-off water must be held and treated on the property then much research is going to be needed.	Somewhat	Some options for treating run-off water identified in case studies. Future research required - NSW DPI?
Conversion of open to closed hydroponic systems	Somewhat	Demonstrated at Site 1 in stage 2 of conversion. Also covered in previous HAL project VG09073 'National greenhouse waste-water recycling project'.
Alternative growing media made from renewable resources and able to be recycled	Not within scope	Potential future HAL project in collaboration with researchers in NSW DPI.
Potential for commercial composting of cocopeat slabs after use. Some growers bury old slabs, some spread around soil grown crops, some give to friends who are still growing in soil. Could be disease issues, potential for local composters to be involved.	Not within scope	Potential role for Compost for Soils? Future HAL project in collaboration with compost and pathology researchers in SARDI and NSW DPI? Potential role for local council?
Possibility of developing systems for recycling rockwool growing media	Not within scope	Potential funding from NRM board, Care for Country, local council or rockwool suppliers?
Monitoring irrigation with probes in growing media	Not within scope	Automated irrigation monitoring is more common in high technology greenhouses. Growers learning the basic management of hydroponic systems better off relying on manual monitoring when learning the system.

4. Technology transfer

Grower days

Grower days were held at the demonstration sites in April 2009, June 2010 and November 2011 and were attended by current and prospective hydroponic growers, consultants, re-sellers, seed company representatives and other industry personnel. Attendees walked through the sites and learnt how the conversions were undertaken, viewed the equipment used, the crops being grown, the capture, treatment and re-use of run-off water and the returns being achieved since converting to hydroponics. Since meeting the owners of the demonstration site, several growers have made direct contact with the owners and repeat visits to learn more about the sites and the progress since the completion of the project.

Newsletters

- Hydroponic conversion project Issue 1, June 2009
- Hydroponic conversion project Issue 2, February 2011

Industry publications

- 'Field demos support hydroponic conversion', The SA Grower, April 2009
- 'Conversion project focuses on effective hydroponic set-ups', The SA Grower, June 2011

Conference presentations

- 'Improving greenhouse systems and production practices (greenhouse production practices component)', Australian Greenhouse and Hydroponic Association national conference, Sydney, 2009 (poster)
- 'Manual for simple hydroponics', Protected Cropping Australia national conference, Adelaide, July 2011 (oral)

Grower training

Dr Kaye Ferguson collaborated with Mr Domenic Cavallaro, National Technical Manager, Stoller Australia in delivering hydroponic training as part of HAL project VG09087 'Capacity building in the Australian vegetable industry through people development', run by Arris Pty Ltd. A series of four presentations were delivered between June and August 2011.

Grower group presentations

- 'Report on International Symposium on Soilless Culture and Hydroponics', Virginia, South Australia, January 2009
- 'Hydroponic conversion project update', Virginia, South Australia, February 2011

Grower visits

- European study tour – Peru and Spain, 2008
- Grower study tour – Spain and The Netherlands, 2010 (in conjunction with VG09112)
- Sydney Basin, New South Wales, 2008 and 2009 (in conjunction with VG05094)
- Mid north coast, New South Wales, 2010
- Perth region, Western Australia, 2010 (in conjunction with VG05094)
- Carnarvon region, Western Australia, 2011

5. Recommendations

5.1 Scientific and industry

Growers should carefully consider conversion to hydroponics and enter with realistic expectations. The best practice manual compiled during this project stresses the importance of understanding that hydroponics is just one part of a crop production system. It is critical that growers realise that hydroponics does not offer complete control of the crop, grow the crop for them or change the greenhouse climate. Growers need to have an overall plan and a realistic financial analysis that will enable them to predict a time to get a return on investment in hydroponics and determine if it is a viable option for their business.

It is recommended that a thorough listing of suppliers to the protected cropping and hydroponic industries be made available to current and prospective hydroponic growers. A potential avenue for this list is via Protected Cropping Australia's website.

Sustainable methods of managing waste products from a hydroponic system also needs to be investigated – particularly nutrient rich run-off water and used growing media.

Further funding opportunities of this type should be offered to the industry. Often major changes in an industry require courageous and forward thinking growers who do not necessarily have the capital to make such risky changes. The levy and VC funding process gives growers the support they need to change practices on individual farms than can then lead to benefits for the industry as a whole. Growers generally respond well to the positive experiences of other growers and demonstration of research outcomes on commercial properties is an extremely valuable extension tool.

5.2 Further work

Knowledge gaps were identified as part of this project (see section 3.8). While many were addressed, the following were out of the scope of this project and should be addressed with future research:

- Developing sustainable growing media, made from renewable resources and able to be recycled.
- Investigating the potential for recycling growing media, such as commercial composting of cocopeat slabs after use and systems for recycling rockwool.
- Quantifying the quality and consistency of growing media between the various types and sources would enable growers to make more informed growing media choices. This would include infiltration rates, water holding capacity, compaction rates, ability to reuse or recycle.
- Quantifying the parameters for management of different media for different crops.
- Effective and economical disinfection of water for low-medium technology greenhouses
- Limitations in hydroponics with different water sources.
- Management of run-off water from greenhouses.

6. Acknowledgments

We wish to thank the numerous collaborators and growers involved in the development of the manual. In particular the demonstration site growers, who allowed open access to the grower community and provided open and honest accounts of their experience. Even though the project is now completed, the grower continues to allow access to the demonstration site for other growers interested in converting to hydroponics. This ongoing access is an in-kind contribution by the grower to the sustainability of the greenhouse industry for which the project team are very thankful.

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