Project title:	The development of an experimental deep pool hydroponics system to investigate its potential for cut flowers.
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Project leader:	Lyndon Mason, LRM Horticultural Services Ltd
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Key staff:	Lyndon Mason Paul Challinor
Location of project:	
Industry Representative:	Graham Whitehead Whiteheads of Boston The Nursery, Wortelys Lane, Boston Lincs, PE21 7JF
Date project commenced:	30th March 2015
Date project completed (or expected completion date):	31st January 2017

DISCLAIMER

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

AUTHENTICATION

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

[Name]

[Position]

[Organisation]

Signature .... Date ....

[Name]

[Position]

[Organisation]

Signature .... Date ....

Report authorised by:

[Name]

[Position]

[Organisation]

Signature .... Date ....

[Name]

[Position]

[Organisation]

Signature .... Date ....

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GROWER SUMMARY

Headlines.

- Column stock production has been more challenging than other cut flowers in deep pool hydroponics owing to disease issues and a high oxygen requirement in the solution.
- However, two years of trials have shown that deep and shallow pool hydroponics seem to be possible systems for cut flower production although engineering solutions are now needed to develop the system on a commercial scale.
- The production of column stocks could be possible in vertical systems (eg aeroponic tubes) but a bespoke support system would need to be developed.
- It is possible to produce column stocks in tulip pin trays using a clay pellet substrate but without an engineering solution to provide crop support, this system results in bent and hence unmarketable stems.
- The production of stocks is possible in pots or modules on an ebb and flood bench system without the need for crop support.

Background

The control of *Fusarium oxysporum* is a major issue for flower growers, especificationially those producing *Matthiola incana* (column stocks) and Lisianthus. Despite a number of AHDB funded projects, the only reliable control is still the expensive and time consuming technique of steam sterilisation, but even this is only a partial cure and large losses can still be seen in steamed glasshouses. In an attempt to overcome these issues the industry has been looking at the possibility of moving completely out of soil into a hydroponics system. The preferred option was some form of solution hydroponics rather than substrate hydroponics and the simplest system seemed to be deep pool hydroponics where the crop is grown on floating rafts in a large pool of water 25 to 30 cm deep. After a trip in December 2014 to look at lettuce production in deep pool hydroponics, Phil Collison of J A Collison and Son decided to construct a small trial pool (7 m x 3.8 m) in order to undertake AHDB funded trials during 2015. There was very little documented work on the production of stocks in a solution hydroponics system and none in deep pool. The purpose of the first year trial (2015) trial was therefore to simply explore some of the basics of production to determine if a marketable crop was even possible. The second year trial (2016) built upon the findings of the 2015 results as well as looking at a number of other potential systems. During the 2015 and 2016 trials other techniques emerged such as producing crops using a

LECA (lightweight expanded clay aggregate) and growing in modules (eg 9cm pots) on an ebb and flood system. These techniques were further investigated in 2017 and 2018.

Summary

YEAR 1 (2015)

The deep pool hydroponic trial facility was constructed in December 2014 and was filled with water in mid-March 2015 ready for the trial to commence in late March 2015.

A number of different floating trays were made from 600 mm x 400 mm x 25 mm dense polystyrene sheets which enabled both plugs and blocks to be investigated. The nutrient status was controlled by an existing "Heron" controller using a traditional A and B tank as well as concentrated nitric acid for pH control. The initial nutrient recipe was drawn up by Paul Challinor of May Barn Consultancy and this was slightly modified for the use of either reservoir or mains water (see table 6 and 7). The water was constantly circulated and entered the pool via a perforated pipe at one side of the pool and was drawn out by a similar perforated pipe at the other side. Oxygenation was initially provided by a "Venturi" which introduced air into the solution. The first plantings were a mixture of stocks propagated in both blocks and plugs, floats of lettuce blocks to act as a "check" specificationies as well as blocked statice and Lisianthus plugs.

It soon became clear that the stocks were not thriving and while the other specificationies (especificationially the lettuce) were growing away very vigorously, the stocks looked very sick. The block propagated stock plants initially seemed to be performing better, but as soon as the roots reached the water they began to turn brown and decay. This contrasted starkly with the lettuce which were ready to harvest within a few weeks and had very vigorous, healthy white roots. This clearly demonstrated that there was no fundamental problem with the pool design but in its current form it was obviously not conducive to the production of column stocks.

A number of brassica were then planted to determine if the system was suitable for Cruciferae (the same family as stocks) in general in the deep pool system. A modified air gap was also introduced to some of the stock trays so that the block or plug was not directly sitting in the water. Aster, ericoides and chrysanthemums were also planted at this stage to broaden the assessment.

A month later the brassica (including, cabbage, sprouts and cauliflower) had put on substantial growth, the aster ericoides and lettuces were thriving but the stocks continued to die. None of the changes that had been made seemed to have made any difference but there were a few random stock plants that had made a marketable flower despite those

around them being either dead or very sick. This suggested that stocks have the potential to thrive in the system with further development of the set up.

After researching the issue further one factor that kept coming up was oxygenation of the water, and there was a suspicion that perhaps stocks required more oxygen than the other crops that were growing in the pool. Accurate oxygen measuring kit and some additional oxygenating equipment in the form of air pumps and air stones were obtained to test this theory. Without additional oxygenation (beyond the venturi system) initial measurements of dissolved oxygen were low (around 2 mg/l or 20% saturation) but once the air stones were introduced, the area immediately around the stone rose to around 8.5 mg/l (85% saturation) and the concentration a few feet away from the stone rose to around 6 mg/l (60% saturation). Soon after increasing the oxygen concentration positive results were seen, with the stock plants immediately above the air stone producing both healthy leaves and more significantly, healthy white roots. However this positive effect was very localised with plants growing two rafts away from the air stone being no better than before even though the oxygen saturation had increased three fold. This clearly demonstrated that stocks seem to need a much higher oxygen concentration than anyone had initially appreciated.

Unfortunately two weeks later some of the healthy plants in the floats over the air stones began to wilt. Closer inspecificationtion showed that the problem was in the stem base which resulted in the roots and stem being detached from one another. This was subsequently confirmed by STC plant clinic as being *Phytophthora* and a recommendation was made to apply metalaxyl as Subdue to the pool. Unfortunately because it was by now so late in the season, no more plugs could be obtained so it was only possible to look at the effect of Subdue on the existing plants rather than a new batch. However the results of the Subdue did seem to be have a marked effect and very few additional plants seemed to succumb to *Phytophthora* although those already infected did not of course recover. By the end of September a number of flowering stems had been achieved and since the addition of the Subdue, it seemed that the positive effect of the air stones was wider than just the float immediately above them.

In addition to the main deep pool trial a small secondary trial was undertaken in three 1.2 m x 1.2 m shallow pools which are only 10 cm deep and are designed to be used with rolling tables. This was started very late in the season so only one round could be produced hence the results must be treated with caution. However, one of these shallow pools had the addition of an experimental form of electrolysed water which allows free available chlorine (FAC) to be released into the solution and this produced some of the best stems of the season although they did not crop until late October.

To summarise, for stocks in the deep pool hydroponics system, none of the earlier variables that were investigated i.e. plugs or blocks, different forms of air gap (or no air gap), different varieties and different planting dates made any difference to the performance of the plants. It was only the introduction of additional oxygen bringing the level up to around 8 mg/l (80% saturation) that started to result in the production of marketable stems even though some of these subsequently succumbed to *Phytophthora* before Subdue was introduced to the water.

The additional trial looking at shallow pool hydroponics has given an indication that it may also be a system that can be utilised for column stock production but as with the deep pool trials it needs to be further investigated to ensure that the encouraging results obtained at the end of the 2015 trials can be both repeated and replicated.

YEAR 2 (2016)

The second year of trials concentrated on just column stocks and incorporated two of the key findings of year 1, i.e. high oxygen concentrations and fungicides to control oomycete disease. These were applied from day 1 of planting in the deep and shallow pool trial. In order to better control the pH and nutrient status, a new IntelliDose controller was fitted complete with peristaltic pumps to deliver the A & B tank nutrient as well as the nitric acid.

Air stones were again used to oxygenate the water and by careful placing of the stones an oxygen gradation was created across the trial. The results of this clearly verified the findings of the 2015 trial and showed that high levels of oxygen in the water are required to produce a healthy root system and subsequent good quality flowers. The use of oomycete fungicides also seemed to adequately control root and stem diseases in the 2016 trial.

The 2016 trials showed that by the use of appropriate fungicides and high oxygen levels in the water, it is possible to produce marketable stems of column stocks in both deep and shallow pool systems. However, in order to now move from a small trial to a commercial scale system, an engineering solution would need to be developed to adequately oxygenate the water to an appropriate level. This will be more difficult with a shallow pool than a deep pool system owing to having a large number of units that all need to be individually oxygenated rather than the one large single system required by the deep pool. It may also be possible to redesign the floats to, for example, have an air gap when using plug-grown in net pots.

It was also clear from both the 2015 and 2016 trials that the plants need to be supported, and if the floats are moved around the system from planting to harvest (as is the case with deep pool lettuce production) the support system would probably need to be an integral part of each individual float. This would also require a commercial engineering solution to resolve the issue.

In addition to the deep and shallow pool trials in 2016, a trial to investigate a vertical aeroponics system was undertaken. While the quality of the stems indicted that it is possible to produce stocks in such a system, a crop support system would need to be devised. This is not an insurmountable issue and the Project Manager has seen support systems used in other vertical hydroponic systems, however careful costing would need to be undertaken before embarking on such a system.

Following on from a very encouraging demonstration seen at Greenmount in the spring of 2016, a trial was set up to look at the use of extruded clay pellets (LECA) as a reusable substrate in tulip pin trays as an ebb and flood system. Two rounds were produced using this system and encouraging results were obtained where the water was drained away completely by using an ebb and flood drain plug. Further trials were the undertaken using LECA substrate during 2017 & 2018.

Propagation in modules was also investigated using 4.5, 5.5 and 9 cm net hydroponic pots and 4 cm oasis blocks. None of these modules showed any advantage for the deep and shallow pool systems. Perhaps the most surprising result of the 2016 trials was the fact that high quality (and apparently self-supporting) stems of stocks were produced in a 9 cm net pot using what can only be described as a "Heath Robinson" ebb and flood system. This was a result that warranted further investigation using commercial ebb and flood system.

YEAR 3 & 4 (2017 and 2018)

A further 2 years of trials were undertaken on growers holdings to further investigate the use of LECA pellets and the production of stocks in modules on ebb and flood benches.

The LECA trials were undertaken at J A Collison & Son (with an additional small trial at Belmont Nursery in 2018) The bespoke trial system used in both years was developed by J A Collison. It enabled a 1.2 m x 1.2 Mm mobile bench insert (the same as those used in the earlier shallow pool trials) filled with LECA pellets, to be flooded on a regular basis (for one minute, six times per day) and the nutrient solution then drained back into a catchment tank. In 2017, two rounds of crops were produced, the first round using a nutrient solution electrical conductivity (EC) of 1.5, 2 and 2.5. While all of the different EC levels produced stems of a potentially marketable specification regarding length and weight, the lowest EC produced severe symptoms of what was believed to be Manganese deficiency in the first planting. As the other two EC levels did not seem to cause any issues with the crop, a decision was taken to just use the higher value (2.5) in subsequent trials. All of the subsequent LECA trials at J A Collison produced stems that exceeded the required specification in terms of stem strength, and both stem and flower spike length.

However, while the LECA system seems to provide an ideal air and water balance which produces strong healthy roots in stocks, it does not provide a strong enough support structure to the roots as would be the case in soil (or compost), which means that the stems cannot support themselves, leading to bent and curved stems making them effectively unmarketable. Therefore until an engineering solution can be found to overcome this problem of crop support, column stock production in a LECA substrate is unlikely to be adopted by the industry.

The 2017 trials investigating the possible production of column stocks in modules on an ebb and flood bench were undertaken at Neame Lea nursery. The first planting was made in week 2 into 18 hole packs (with an overall dimension of 31 cm x 54 cm) and 9 cm pots in 18 hole carrier trays (about 30 cm x 53 cm). This gave a spacing of around 107 plants per sq/m for the packs and 117 plants per sq/m for the pots. The varieties planted were Mathilda cream and Figaro lavender with a second planting being made in week 6 and a third in week 10, both using Francesca. All plantings were then split into two and one half grown on in a warm environment (about 16°C day and night) where tulips were being grown and the other half in a cold environment (around 5°C day and night) where hardy bedding plants were being grown.

All of the plantings produced a marketable crop and unlike the LECA trials no support was required in order to produce straight stems. As expected, the colder crop took longer to produce a marketable crop (in fact the week 6 cold planting of Francesca flowered at the same time as the week 10 warm planting of the same variety) than the warm crop, and also produced stronger heavier stems. The weight and strength of the cold crop was in fact comparable to the stems produced in the LECA trials. These trials demonstrated that module production on an ebb and flood system is a viable production technique and this has in fact been used on a commercial scale during 2018.

Financial Benefits

To provide an economic assessment of a deep pool hydroponics system is not easy because for it to be economically viable a crop would need to be produced all year round as is the case with lettuce. At this stage it is not clear what crop could be produced in summer and autumn to follow on from the stocks.

The fact that the deep pool system still requires some fundamental engineering solutions (to increase oxygenation and develop bespoke trays with integral plant support) means that it is also not possible to provide an accurate cost for setting up a commercial system. However, as a guide, to set up a 0.1 ha deep pool hydroponic system, the cost would be an estimated £5 per sq/m for the liner (£5,000 for 0.1 ha), around £25 per sq/m to concrete the floor (£25,000 for 0.1 ha), £30,000 for the irrigation plus control system and a further £5,000 for labour and other miscellaneous costs. This would make a total ball park figure of around £65,000 to set up a 0.1 ha (quarter of an acre) basic deep pool system.

Regarding the trials at Neame Lea, the value of a column stock crop alone would not justify the installation of an ebb and flood system, but is applicable to existing systems (perhaps being used for tulips or bedding) where the production of stocks would fit a production window when the system was not being fully utilised with the other crops. In such a situation it was estimated by the growers undertaking these trials that the main extra cost of using a module system, i.e. the growing medium, was offset by not having to steam the soil, which is the case in a normal soil based production system. There could also be labour saving costs in the pot system assuming the nursery has an automated potting system that can transplant the plugs into the module.

Action Points

- Consider small scale trials of deep and shallow pool hydroponics for cut flowers but further engineering solutions are required to develop this on a commercial scale
- Vertical aeroponic and hydroponic systems are a possibility for the production of column stocks but support is required and the chosen system would require careful economic evaluation (for further details see .http://www.aponic.co.uk/ and http://www.saturnbioponics.com/trial-crops/column-stock-flowers/)
- Growers could consider trialling tulip pin trays with a clay pellet substrate (LECA) but an engineering solution needs to be found to support the crop.
- If the nursery already has an ebb and flood system in place the grower could consider producing column stocks in a module system such as 9 cm pots.

SCIENCE SECTION

Introduction

Most protected cut flower production in the UK (excluding bulbs such as lilies in crates and tulips in "water") still takes place in the glasshouse soil (known as border soil by growers) and employs an intensive cropping regime that tends to favour the build-up of diseases. The most troublesome disease in recent years has been *Fusarium oxysporum* which has resulted in crop losses of over 80% in some protected crops of column stocks (*Matthiola incana),* which is currently the most important spring and summer UK protected cut flower crop. It can also be a serious problem in Lisianthus production. Despite a number of growers' own trials and AHDB funded work, steam sterilisation is still the only option for controlling this disease but it is expensive (both in terms of fuel and labour), not sustainable in the long term, and does not fully control the disease especificationially if soil conditions are not perfect at the time of steaming.

A radical alternative method of production would be to move out of the soil and grow the crop in some form of hydroponics system. This is an alternative that has been investigated by a number of key column stock growers (representing about 70% of the total UK stock area) over the past few years. In order to move this forward the AHDB commissioned a review of previous work on hydroponics and this was undertaken by Dr Paul Challinor in 2013/14 (PO 018). After studying the findings of the review and a very timely visit to a South Coast lettuce producer, the growers decided that deep pool hydroponics was the system that they most wanted to investigate further. Deep pool hydroponics is a system where young plants are suspended from pierced floating rafts (e.g. polystyrene) over a reservoir of water which is usually 25 to 30 cm deep.

Substrate hydroponics (e.g. growing in peat or Coir) is a more established method of production and has been trialled by some growers in the past couple of years. While column stocks appear to grow well in these systems, the growers felt that it had a number of inherent problems such as cost, sustainability of supply, disposal issues, the need for sterilisation etc. Because of these issues, the growers felt that production in water is the way forward, with deep pool hydroponics appearing to be the simplest and most practical system currently available. However, very little information was available about the growth of cut flowers in such a system and in order to further their knowledge a grower trip was organised to look at a South coast lettuce deep pool facility.

The outcome of this trip was a decision to trial deep pool hydroponics by the building of a small trial pool (courtesy of Phil Collison of J A Collison and Son) and an AHDB-funded one year trial with the aim of determining some basics of production, including types of tray (floats), plugs or blocks, and nutrient recipes.

Materials and methods

YEAR 1 (2015)

The trial was undertaken on a commercial nursery in a small glasshouse compartment measuring 6 m x 10 m, separated from the main glasshouse via a glass partition and with its own independent manual vents. The deep pool hydroponic trial tank was built to fully fill the compartment and measures 7 m x 3.8 m with a 1 m walkway all the way around the tank to enable easy access to all areas of the pool throughout the trial (Figure 1). The nutrient and pH control was achieved by using a Heron MPD-4 controller (Figure 2) which had been moved from another glasshouse on the nursery. The nutrient controller uses the traditional A and B tank but rather than having a separate mixing tank, the actual deep pool was considered to be the mixing tank with the nutrient being injected directly into the water in the pool (see tables 6 and 7 for the actual recipe in the A & B tank). The pool was constructed in late December 2014 by the nursery's own staff and was filled with water for the first time on 21st March 2015. The water was constantly circulated within the pool by a pump sucking water out of the pool via a 50 mm plastic pipe with 15 mm holes drilled 1 m apart. This pipe ran along the whole of right hand side of the pool (as in Figure 1). The water was re-injected by an equivalent pipe that ran all the way along the left hand side of the pool. A Venturi was fitted to the outlet pipe from the pump in order to introduce oxygen into the pool.

Figure 1. The experimental deep pool hydroponic facility in December 2014.

Figure 2. The EC and pH controller used for the trial.

The crop was planted in polystyrene floats which were made from 400 mm x 600 mm x 25 mm sheets of dense polystyrene sheets. These were either drilled out with a 18 mm drill for planting the plugs, and was just the right size to support the size of plugs used i.e. those from a standard 600 mm x 400 mm, 600 cell polystyrene tray (Figure 3) or a square hole created with a bespoke cutter made from 45 mm x 45 mm box iron for planting with blocks (Figure 4). Each float had three rows of five holes, with the holes being spaced at 6.5 cm from the edge of the float to the middle of the hole and 12.5 cm from the centre of each hole to the next. The aim of this spacing was to achieve a density of 64 plants per sq/m which is the norm for a soil grown crop.

Figure 3. Polystyrene floats used for the plug plants.

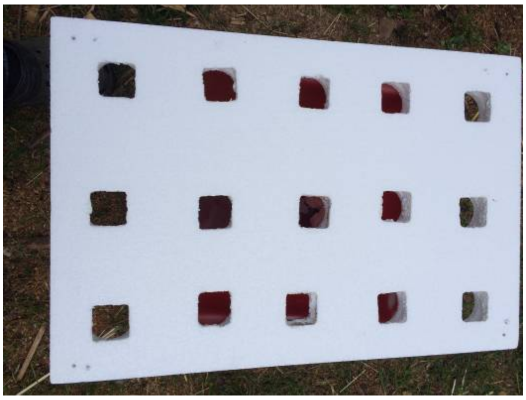

Figure 4. Polystyrene floats used for the block plants.

From information obtained from lettuce growers it was thought that the plants may require an air gap underneath each plug, and this was achieved by drilling a 50 mm hole in either a 25 mm thick or 10 mm thick sheet of polystyrene (Figures 5 and 6), with a view to attaching these under some of the plug and block floats at planting.

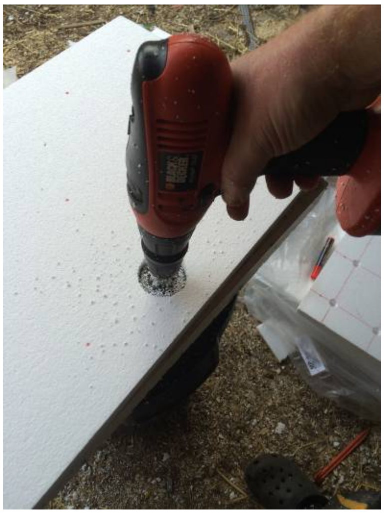

Figure 5. Drilling out the 50 mm air gaps.

Figure 6. A completed float of 50 mm air gaps.

During the 8 months of the trial, a number of different plantings and modifications were made to the trial and the clearest way to present these is under a date heading for each action which can then be clearly tied into the results section.

Trial timeline

On March 5th 2015, plugs of column stocks (variety Figaro lavender) were transplanted into 4 cm peat blocks to be grown on and then transferred to the block floats once they were large enough.

The first batch of floats were planted March 27th which consisted of: 14 floats of blocked stocks, four of which had 25 mm deep air gaps and a further four had 10 mm air gaps; three block floats of lettuce of which one had a 25 mm air gap; 39 floats of plug column stocks (variety Figaro lavender) of which five had 25 mm deep air gaps and a further five had 10 mm air gaps; and finally three floats where the plugs were planted into the empty trays the plug plants were propagated in. The remaining area of the pool not planted with floats was covered with a black reservoir liner to exclude light and reduce algal growth (Figures 7 and 8).

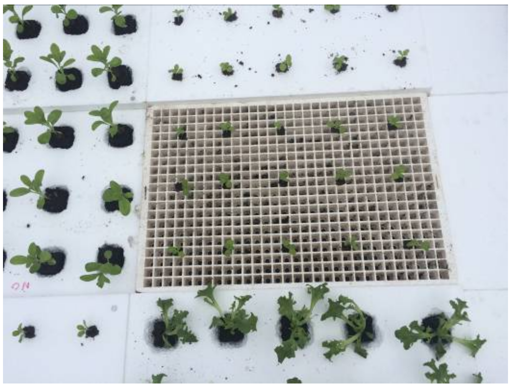

Figure 7. Newly planted floats showing plugs and blocks.

Figure 8. Overall shot of the newly planted floats.

In April, of the many sick-looking trays of stocks were removed from the pool and modified air gaps were added to the floats that showed some promise. The modified air gaps were comprised of either the original 50 mm gaps with added channels to join them together (Figure 9) or thin strips of 10 or 25 mm polystyrene (Figure 10).

Figure 9. Modified air gap by the addition of channels to produce uninterrupted air flow.

Figure 10. Air gap created by the use of thin strips of polystyrene.

In addition, 18 new floats of plug grown column stocks (Figure 11) were planted, of which two had the modified 50 mm air gap, two had the 25 mm strips and a further two had the 10 mm strips. For the plugs that did not have an air gap, care had to be taken when planting to ensure that the plug was inserted to the bottom of the float in order for the roots to be able to take up water. The trays with an air gap required overhead irrigation (in this case using a watering can) until the roots had grown long enough to touch the water.

In order to rule out any issues with the brassica family per-se (column stocks are a member of the cruciferae family) a float each of cauliflower, cabbage, calabrese and sprouts were planted (Figure 12). Three floats of Lisianthus were also planted with one of them having a 25 mm thick air gap.

Figure 11. The pool on April 27th 2015 showing newly planted floats and the remainder of the original planting.

Figure 12. Floats with newly planted brassica plugs.

Three trays of blocked aster ericoides cv Cassandra (Figure 13) and one tray of blocked statice were planted on May 21st 2015. Two of the original three trays of lettuce were removed from the pool (Figure 14).

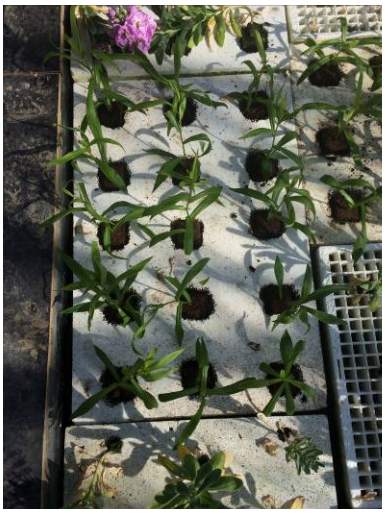

Figure 13. A float of blocked aster ericoides cv Cassandra planted on May 21st 2015

Float 14. Lettuce removed from the pool. These were planted on March 27th 2015.

A dissolved oxygen meter (Hanna Instruments model HI 98193) was purchased to enable the oxygen levels in the pool to be monitored throughout the remainder of the trial. The pool was cleared of all of the floats on June 12th, except for the Lisianthus, asters and statice. It was drained of water, cleaned and refilled with new water (this time primarily mains water) and replenished with nutrients (using the recipe for mains water at table 7). The floats to be kept were placed on wooden supports laid across the pool (Figure 15) while it was being cleared out before being re-floated in the fresh solution (Figure 16) and the roots were therefore out of the water for about 5 hours.

Figure 15. Aster, Lisianthus and statice removed from the pool while it was cleaned.

Figure 16. Aster, Lisianthus and statice re-floated after pool was refilled.

June 16th 2015

Another 18 floats of plug grown column stocks (variety Figaro lilac) were planted June 16th, and a further nine trays of Lisianthus plugs (variety Picolo 2 deep blue) were planted the day after.

In order to increase the oxygen levels, a large aquarium pump (Figure 17) and large air stones (Figure 18) were purchased and set up in the pool at the end of June. Initially four air stones were placed in the pool and these were attached to bricks with cable ties in order to keep them submerged.

Figure 17. Air pump to increase oxygen levels in the pool.

Figure 18. Air stone attached to brick and placed under individual floats.

Nine new floats of a wide range of column stock varieties were planted at the end of July. These were Centum white, Centum Apricot, Centum deep blue, Centum lavender, Jordyn white, Jordyn apricot, Jordyn red, Lucinda rose and Lucinda red. These were from a different propagators and because they were supplied in a smaller plug, new floats had to be made with the same spacing as previously but with a 15 mm hole to support the plug. Another air pump and eight additional air stones were purchased and the stones were placed under random trays throughout the pool. Nine plug floats of Centum cream were also planted.

July 20th and 21st, three floats of chrysanthemums (variety Chivenor) as well as two further floats of aster ericoides plugs and little Gem lettuce in blocks were added to the pool.

The project manager had been working with a company developing electrolysed water for a number of different uses in the Agri food sector. Discussions about the deep pool hydroponic trial resulted in a suggestion to try using one of their experimental solutions to add to the hydroponics solution, to create a level of free active chlorine (FAC) that will be harmless to the plants but at a high enough concentration to control both algae and diseases. In order to trial this theory an additional experiment was set up at the end of July using three shallow pools which were obtained from a local bulb nursery, designed to sit within the frame of a standard rolling bench. The dimensions of each pool was 1.2 m x 1.2 m x 10 cm deep and they were positioned on beams of wood that spanned the far end of the main pool (Figure 19) They were filled using solution from the main pool. Each of the shallow pools was supplied with additional oxygen via a pump and two long air stones (Figure 20).

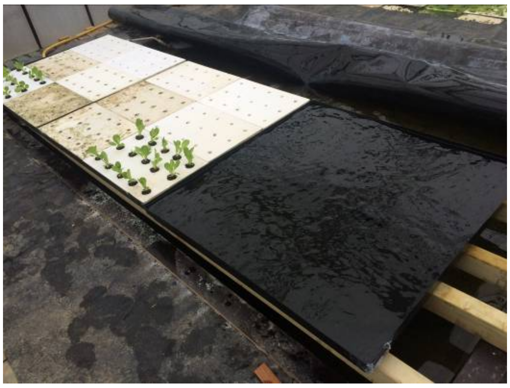

Figure 19. The three additional shallow pools supported on beams above the main pool.

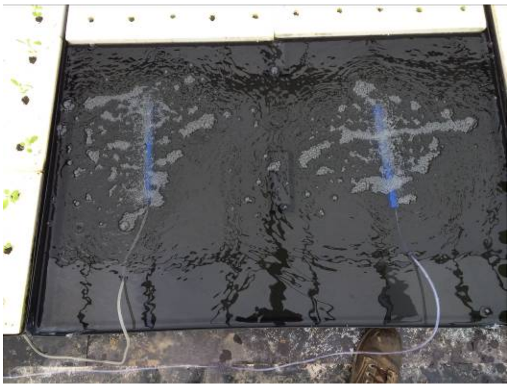

Figure 20. A single pool showing the 2 long air stones to increase oxygen levels.

The three shallow pools were planted up with one float of blocked lettuce and 5 floats of plug stocks, variety Centum red (Figures 21 and 22). An additional 9 trays of column stock, Anytime red, were also planted in the main pool. Owing to no more plugs being available from the propagators, this was the last planting to be made in 2015.

Figure 21. The shallow pools partially planted on July 29th 2015.

Figure 22. The shallow pools fully planted on July 29th 2015.

Subdue (metalaxyl-M) was added to the main pool at a rate of 1 ml per 100 l of solution on August 10th. It was hoped that we could add the electrolysed concentrate to the shallow pools as soon as the crop was planted but unfortunately owing to some logistical issues it was not delivered until August 13th 2015, some weeks after the crop was planted. The plants in pool three looked very sick (owing to an issue with the air stones) so this was abandoned and the electrolysed solution only added to pool 1 (25 ml with the aim of producing a FAC level of 0.5 to 0.6 ppm) with pool 2 acting as a control.

The lettuce floats were removed from the shallow pools at the beginning of September because they had reached maturity. Pool 1 was topped up with another 10 ml of electrolysed water concentrate. At the end of September (27th), most of the floats were cleared from the main pool except a few trays of Anytime column stocks, chrysanthemums, asters and statice, and at the beginning of November (6th), samples of Centum red were harvested and taken to a local packer for vase life testing.

By November 11th, both the deep pool and shallow pools were completely cleared out and all of the floats cleaned, dried and stored away.

The following tables (1-5) show the target values for the nutrients and ratios in the deep pool solution supplied by Dr. Paul Challinor, May Barn Consultancy Ltd.

Table 1. Hydroponic cut flower root zone pH and EC targets

RAG Chart: Protected Flower Crops	Red: Likely to result in plant damage	Amber: Likely to result in nutrient deficiency	Green: at or near the optimum concentration	RAG Chart: Protected Flower Crops
pH	< 5.5	6.0	> 6.5	Target range: 5.8-6.2
EC µS / cm	< 1,800	2,500	> 3,500	> greater than < less than

Table 2. Hydroponic cut flower root zone main element target concentrations

RAG Chart: Protected Flower Crops	Red: Likely to result in plant damage	Amber: Likely to result in nutrient deficiency	Green: at or near the optimum concentration	RAG Chart: Protected Flower Crops
Major Elements mg / litre				> greater than < less than
NH4-N	0	2	> 10	As low as possible
NO3-N	150	200	> 250	
P	20	30	> 50*	*Induced Zn+Cu deficiency likely
K	< 200	250	500	Toxicity: rare
Ca	150	200	> 300	
Mg	< 30	40	> 60	High K inhibits Mg absorption

Table 3. Hydroponic cut flower root zone unwanted ion target concentrations

RAG Chart: Protected Flower Crops	Red: Likely to result in plant damage	Amber: Likely to result in nutrient deficiency	Green: at or near the optimum concentration	RAG Chart: Protected Flower Crops
Unwanted mg / litre Ions				> greater than < less than
Na	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Cl	< 100	200	> 400	
SO4-S	< 50	100	> 200	

Table 4. Hydroponic cut flower root zone trace element target concentrations

RAG Chart: Protected Flower Crops	Red: Likely to result in plant damage	Amber: Likely to result in nutrient deficiency	Green: at or near the optimum concentration	RAG Chart: Protected Flower Crops
Trace Elements mg / litre				> greater than < less than
Fe	< 2.0	3.0	> 5.0	
Mn	< 0.3	0.5	> 0.8**	**Toxicity risk higher
B	< 0.3	0.4	> 0.8	
Zn	< 0.3	0.5	> 1.0	Link with P and Mn
Cu	< 0.05	0.1	> 0.2	
Mo	< 0.01	0.03	> 0.1	

Table 5. Hydroponic cut flower root zone main element nutrient ratios

RAG Chart: Protected Flower Crops	Red: Likely to result in plant damage	Amber: Likely to result in nutrient deficiency	Green: at or near the optimum concentration	RAG Chart: Protected Flower Crops
Nutrient Ratios				> greater than < less than
K:N	> 1.6	1.25	< 1.1	
K:Ca	> 1.6	1.25	< 1.1	
K:Mg	> 7.5	6.0	< 4.0	
K:Na	> 3.0	1.25	< 1.1	Important in recirculation
K:Cl	> 3.0	1.25	< 1.1	Important in recirculation

Based on the water analysis at Appendix I, the following nutrient recipe was used for the initial solution made up from rain water (Table 6).

Table 6. Recipe for initial solution made from rainwater

A TANK Compound	Weight	B TANK Compound	Weight
Calcium nitrate 19%Ca, 16% N	4.0kg	Potassium nitrate 38%K, 13% N	3.0kg
Potassium nitrate 38%K, 13% N	0kg	Mono-potassium phosphate 29%K, 23% P	2.5kg
Potassium chloride 50%K, 45% Cl	1.5kg	Magnesium sulphate 10%Mg, 13% S	2.0kg
DTPA iron chelate 6%	225ml	Manganese sulphate 32%	20g
		Zinc sulphate 23%	5g
		Borax 21%	40g
		Copper sulphate 25%	2g
		Sodium molybdate 40%	1g

Notes:

Input EC: 2,000 to 2,200 uS/cm

Tank sizes: 100 litres

Dilution: 1 in 100

Nitric Acid input required to reduce solution pH to 6.0 (range: 5.8 to 6.2)

Based on the analysis of the mains water (Appendix II), the following recipe was used when the pool was refilled with mains water on June 12th 2015.

Table 7. Recipe for solution made up from mains water

ATANK **Compound**	**Weight**	**B TANK** **Compound**	**Weight**
Calcium nitrate 19%Ca, 16% N	4.0kg	Potassium nitrate 38%K, 13% N	2.0kg
Potassium nitrate 38%K, 13% N	1.0kg	Mono-potassium phosphate 29%K, 23% P	1.5kg
Potassium chloride 50%K, 45% Cl	0kg	Magnesium sulphate 10%Mg, 13% S	2.0kg
DTPA iron chelate 6%	250ml	Manganese sulphate 32%	20g
		Zinc sulphate 23%	6g
		Borax 21%	30g
		Copper sulphate 25%	1g
		Sodium molybdate 40%	0.5g

Notes:

Input EC: 2,000 to 2,200 uS/cm

Tank sizes: 100 litres

Dilution: 1 in 100

Nitric Acid input required to reduce solution pH to 6.0 (range: 5.8 to 6.2)

YEAR 2 (2016)

The same facility was used as in 2015 and both the deep pool and all of the trays were sterilised with Peroxyacetic acid under the trade name Hydro Cleanse on the 4th April, before being thoroughly rinsed with clean water (Figure 23). The pool was then filled with nutrient solution ready for planting up the trial (Figure 24). This year the unused area of the pool was covered with 2.4 m x 1.2m x 25 mm sheets of polystyrene rather than a black reservoir liner as was the case in 2015. The polystyrene was both neater than the reservoir liner and also insulated the pool keeping the water cooler. *Metalxyl as Subdue* was added to the deep pool at a rate of 1 ml per 100 L of solution on the 23rd of April and 27th of May. On the 29th June and 8th of August 5 gm of *Paraat (dimethomorph)* was also added to the deep pool .

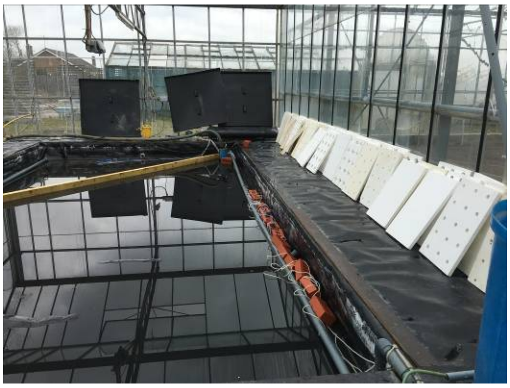

Figure 23 Cleaning and sterilisation of the deep pool facility before starting the 2016 trials.

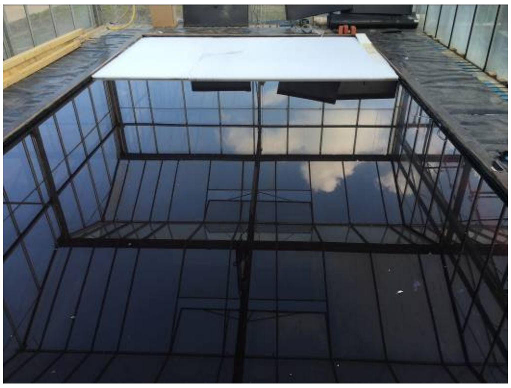

Figure 24 Sterilised pool filled with nutrient solution ready for planting the 2016 trials.

In 2016 a new nutrient and pH controller was purchased and installed. Figures 25 and 26 show an Intellidose system complete with three peristaltic pumps.

Figure 25 New IntelliDose controller from Autogrow systems.

Figure 26 IntelliDose controller installed at the deep pool facility using three peristaltic pumps, one each for the A and B tank and acid supply.

Trial Time Line

The first round of stocks was planted up with the variety Mathilda Yellow on 13th April 2016. Four rows of nine floats of plugs were planted with each of the middle two rows having an air stone under each float, but no air stones under the two outside rows. The reason for this was to try and produce an oxygen gradient across the trays and determine the impact on growth of the plants.

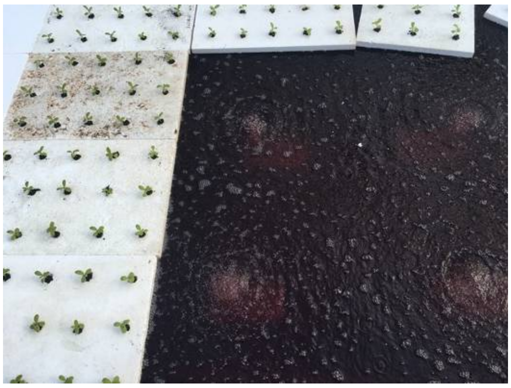

Figure 27 Freshly planted floats on 13th April 2016.

Figure 28 Position of air stones under the centre two rows of floats.

Just over a week later, the three shallow pools were planted up with floats of Mathilda yellow and one float of lettuce per pool (two floats were left empty to plant up at a later date). Each pool had two air stones each to oxygenate the water.

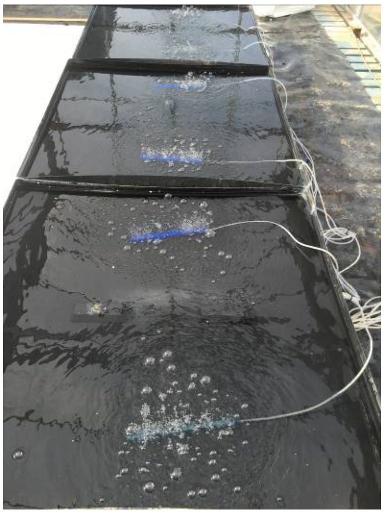

Figure 29 Two air stones within each freshly filled shallow pool.

Figure 30 Shallow pools planted up with 3 floats of stocks and 1 float of lettuce.

Ian and Philip Collison very generously purchased a vertical aeroponics system from Aponics (see aponics.co.uk for more detail) as an additional trial to the main deep pool trial and enabled another element of hydroponics to be investigated in 2016. The system was installed and planted up with Mathilda yellow on 24th April (Figure 31 and 32).

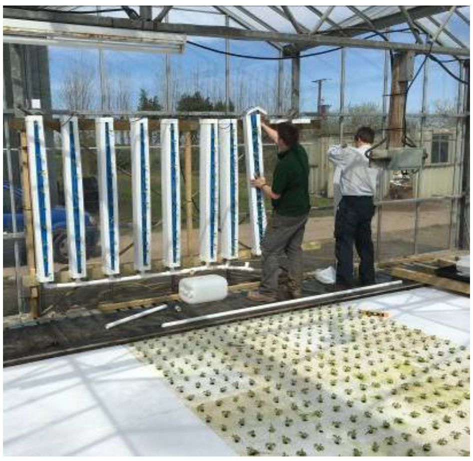

Figure 31 Installation of Aponic vertical aeroponic production system.

Figure 32 Planting column stocks on foam blocks within individual aeroponic tubes.

The two empty floats in each of the shallow pools were planted up with Matilda yellow on May 13th. A corner of the deep pool was also planted up with 10 floats of Matilda yellow plugs and two blocked floats of lettuce. This area of the deep pool was not oxygenated with air stones to provide an area of low level oxygen concentration.

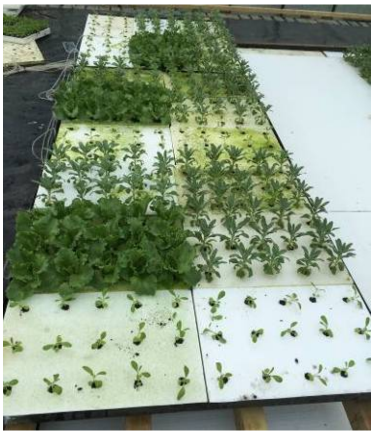

Figure 33 Matilda yellow plugs panted into the 2 empty floats in the shallow pools.

Figure 34 Additional 12 floats planted in an un-oxygenated corner of the deep pool.

The next day two healthy and actively growing floats were moved from the original April 11th planting and swapped with two floats from the May 13th planting in the low oxygen concentration corner of the deep pool, to see what would happen to plant growth.

Figure 35 Two floats from the unoxygenated corner replacing two of the mature floats in the oxygenated area of the deep pool.

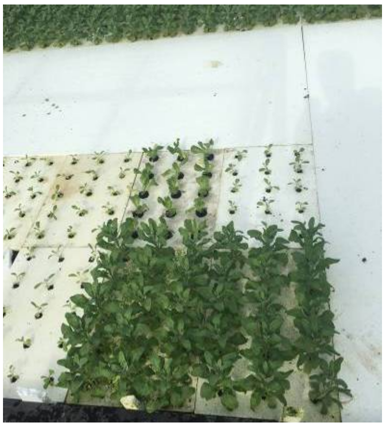

Figure 36 Two mature healthy floats from the oxygenated area swapped with two trays in the unoxygenated area.

Two of the tubes of the aeroponic system were replanted with Centum white on May 17th. In order to ensure that the roots were adequately misted, the plugs were placed deeper into the foam than was the case with the first planting. The output of the misting nozzles was also increased by adjusting the frequency at which the pump was activated.

Figure 37 Replanted plugs showing them deeper in the foam hence ensuring that the roots are adequately misted.

Figure 38 The replanted tube repositioned in the aeroponic system.

In order to support the crop a simple structure of wooden battens and lily wires were place over the crop on May 27th. The wire was secured to the wooden battens by means of cable ties. Please bear in mind that this was a simple solution to meet the needs of this trial and would not be a practical option for a commercial scale crop.

Figure 39 Simple wooden structure to attach the lily wires.

Figure 40 Mature crop supported by the lily wires.

After a visit to look at demonstrations at Greenmount in mid-May, the management group (for the project) requested that the use of extruded clay pellets in tulip pin trays be investigated. On June 13th, this was set up in nine pin trays suspended above the deep pool using a combination of different sized pellets, old Nipla Hydrobak+ style pin tray inserts, and new Parel self-contained pin trays (Figure 42). The two different clay pellets were LECA 4 - 10 mm, described as: "*being a light expanded clay aggregate and a light inert material. It provides a low density drainage layer in planters and can be added to growing media to reduce bulk density and to enhance drainage"*; and LECA 8 - 16 mm described as being: "*light, inert and has a regular rounded profile and an even and regular colour*." Different drain plugs were also used which meant that some trays drained completely after flooding while others retained a reservoir of 2 cm of water in the bottom of the trays. The trays were flooded for 1 minute seven times in a 24 hour period, with water pumped directly from, and draining back into, the deep pool.

The first planting of stocks from the deep pool system was harvested on June 13th (Figure 41).

Figure 41 Harvesting of the crop planted in the deep pool on April 13th.

Figure 42 Stocks planted into tulip pin trays filled with extruded clay pellets.

On June 19th, the three shallow pools were cleared out and three floats in each pool replanted with Anytime white (Figures 43 and 44). It was then intended that one of the three remaining floats would be planted with lettuce and the other two with net hydroponic pots. Two additional air stones were added to each shallow pool making a total of four per pool.

Figure 43 Planting up of the shallow pool floats with Anytime white.

Figure 44 Completed planting of all three of the shallow pools.

In order to see if a stronger root system could be developed to negate the use of crop supports, a number of plugs were transplanted into 4.5, 5.5 and 9 cm net hydroponic pots on June 21st (Figures 45 and 46). A 100% medium grade Coir as well as 4 cm oasis blocks were used. These were then grown on in large plant trays which were watered regularly, and about 1 cm of water was retained in the bottom of the tray.

Figure 45 Plug plant freshly potted into Coir in a net hydroponic pot.

Figure 46 Various sized net pots soon after potting of the plugs.

The large 9 cm pots were purchased by mistake. Initially it was thought that this would be too large to be an economically viable option but the project manager decided to plant up a few to determine their potential anyway. These were spaced pot thick and placed in a shallow tray measuring 80 cm x 40 cm by 4 cm deep. They were watered once or twice a week (depending on weather conditions) with the same solution as was used to top up the shallow pool, and a small reservoir of water was retained (no more than a cm) in the bottom of the tray at all times. These were planted up on June 21st and one float planted in the shallow pool on July 20th. On August 8th the pots left *in situ* in the shallow plant tray were in full flower with strong stems that did not require additional support (Figure 133).

A week later, the deep pool system was planted up with a new round of 36 floats using a mixture of varieties and propagation formats (a full planting plan is included in Figure 49). At this point, the plants in the net pots and oasis plugs were not yet mature enough to be placed in the relevant floats hence these floats were left empty until a later date. The planting of the second round of the deep pool system had been deliberately delayed until the end of June to try and tie in flowering with the CFC Open Day in early August.

Figures 47 and 48. Deep pool floats planted up with plugs. Empty floats are in place for later planting with the net pots and oasis blocks

Centum white in "plug" float	Centum red in net pot	Centum yellow in "plug" float.	Anytime deep rose in "plug" float	Centum pink in net pot	Jordyn deep rose in "plug" float	Anytime white in "plug" float	Anytime yellow in "plug" float	Anytime sea blue in Oasis block
Centum white in "plug" float	Centum red in net pot	Centum yellow in "plug" float.	Anytime deep rose in "plug" float	Centum pink in net pot	Jordyn deep rose in "plug" float.	Anytime white in "plug" float	Anytime yellow in "plug" float	Anytime sea blue in Oasis block
Centum white in net pot	Centum red in "plug" float	Centum yellow in "plug" float.	Anytime deep rose in Oasis block.	Centum pink in "plug" float	Jordyn deep rose in net pot.	Anytime white in "plug" float	Anytime yellow in net pot.	Anytime sea blue in "plug" float
Centum white in net pot	Centum red in "plug" float.	Centum yellow in "plug" float.	Anytime deep rose in Oasis block.	Centum pink in "plug" float	Jordyn deep rose in net pot	Anytime white in "plug" float	Anytime yellow in net pot	Anytime sea blue in "plug" float

Figure 49 Plan of the new planting of floats in the deep pool showing the different varieties and planting format

By July 4th, the plugs planted into the net pots were large enough to plant into the relevant floats in both the deep pool and shallow pool systems (Figures 50-53).

Figure 50 Root growth of the plugs in the hydroponic net pots.

Figure 51 Net pots placed in float before being floated in the deep or shallow pool.

Figure 52 Root growth of the plugs in the oasis block.

Figure 53 Oasis plugs placed in float before being floated in the deep pool system.

The aeroponic tubes were replanted with 2 tubes of Centum red and 8 tubes of Anytime white on July 13th (Figures 54 and 55).

Figure 54 Close up of an aeroponic tube planted with Centum red.

Figure 55 Freshly replanted aeroponic trial.

The plugs transplanted in the large 9cm diameter net pots on June 21st 2016 had by now grown into very strong healthy plants with a good root system. One float of these was therefore transferred to one of the shallow pools on July 20th with the remainder remaining *in situ* in the plant tray (Figures 56 and 57).

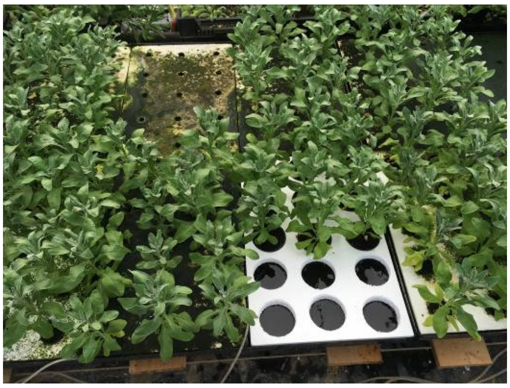

Figure 56 Single float of 9cm net pots in one of the shallow pools.

Figure 57. Remaining 9 cm net pots left pot thick growing in the shallow plant tray.

The tulip pin trays were cleared out on August 11th and modified to ensure that all contained drain plugs that allowed the water to drain away completely after they had been flooded (Figures 58 and 59). They were then replanted using Anytime sea blue.

Figure 58 (left) and Figure 59 (right) Second planting of the tulip pin tray trial using extruded clay pellets as the substrate.

At the end of September the deep pool trial and the aeroponics trial were cleared out and the floats and remaining equipment cleaned up before being stored away (Figures 60 and 61).

Figure 60 Clearing out the 2016 deep pool trial.

Figure 61 Clearing out the 2016 aeroponic trial.

YEAR 3 (2017)

The hydroponics trials undertaken in 2016 showed that there may be potential for producing column stocks in containers (pots or packs) using a bench ebb and flood system. In order to explore this in more detail, a trial was undertaken in 2017 on a commercial facility (Neame Lea Nursery) equipped with modern ebb and flood facilities.

The 2016 trials also looked at producing column stocks in an ebb and flood system using LECA (Lightweight Extruded Clay Aggregate). This followed on from successful trials undertaken at Greenmount College in Northern Ireland viewed by a number of key growers in 2015. A bespoke system was built by J A Collison and Son which enabled three different systems to be investigated in 2017.

<u>Neame Lea Trials</u>

The first planting was made in week 2 into 18 hole packs (with an overall dimension of 31 cm x 54 cm) and 9 cm pots in 18 hole carrier trays (about 30 cm x 53 cm). This gave a spacing of around 107 plants per sq/m for the packs and 117 plants per sq/m for the pots. The varieties planted were Mathilda cream and Figaro lavender supplied by Florensis young plants. A second planting was made in week 6 and a third in week 10, both using Francesca also sourced from Florensis. All plantings were then split into two and half then grown on in a warm environment where tulips where being grown and the other half in a cold environment where hardy bedding plants were being grown. The warm environment was kept at about 16°C day and night with the cold environment being kept at around 5°C day and night. The irrigation of the crop was dictated by the nursery manager who treated the crop of column stocks like any other pot plant grown on the ebb and flood benches.

Figure 62. Stock plugs planted into packs. **Figure 63**. Stock plugs planted into pots

J A Collison Trials

The bespoke trial system developed by J A Collison enabled a 1.2 m x 1.2 m mobile bench insert filled with LECA pellets to be flooded on a regular basis (for one minute, six times per day) and the nutrient solution then drained back into a catchment tank. The trial system is shown in Figures 64 and 65.

Figure 64. LECA trial showing collection tank

Figure 65. LECA trial showing nutrient delivery system and close up of the planted plugs

The first planting was made into the LECA pellets in week 4 using a random planting of a range of varieties including Figaro lavender, Francesca, Deborah and Mathilda cream at a spacing of 64 per sq/m. The first planting investigated three different nutrient levels with the EC set at 1.5, 2 and 2.5. The LECA pellets were flooded for one minute, six times per 24 hour period ie 12 AM, 6 AM, 9 AM, 12 PM, 3 PM and 6 PM. Two of the systems (i.e. an EC of 1.5 and 2.5) were filled with 8-16 mm LECA with the third (i.e. an EC of 2.0) filled with 4-10 mm LECA.

A second later planting was made in week 23 with all three systems being run at the highest conductivity of 2.5, but unfortunately owing to some technical issues with the systems it was not possible to obtain any meaningful results from this second planting.

YEAR 4 (2018)

In 2018, two Norfolk growers (ie J A Collison & Son and Belmont Nursery) decided to conduct further experiments at their own expense to further investigate the use of LECA pellets as a substrate for column stock production. Neither of these trials received any direst funding from the AHDB but owing to their close involvement with the CFC, both growers agreed that the CFC Project Manager could visit on a regular basis, undertake assessments at flowering and incorporate the trial into this final report.

<u>J A Collison Trials</u>

This trial was undertaken using the same bespoke system developed in 2017 (Figure 64). However, the grower wished to simplify the nutrient management in this trial and as such one tank was filled with Sensi Bloom A+B which is a proprietary formulation aimed specificationifically at small-scale hydroponic systems, eliminates the need for sophisticated monitoring equipment and also balances the pH. The second tank was filled with a nutrient solution made up of Kristalon blue 19-16-20 and the third tank used Kristalon white 15-5-20. Each tank was maintained at an EC of as close to 2.5 as possible owing to this apparently being the optimum value in the previous years trials.

The trial was planted in week 5 using a random mixed planting of Deborah, Francesca and Aida white at a spacing of 64 plants per sq/m.

Figure 66. Week 5 planting in LECA pellets.

Figure 67. Close up of the week 5 planting.

<u>Belmont Trial</u>

In 2018 Belmont Nursery decided to further investigate the use of LECA pellets in tulip pin trays and lily trays but this time using an ebb and flood table system rather than the run to waste system that was used in the 2016 trials. A simple system was built, similar to the J A Collison LECA system but using a single ebb and flood bench. Rather than the whole bench being filled with LECA pellets, individual tulip pin trays or lily trays were filled with LECA (as per the 2015 & 2016 trials) and then stood out on the ebb and flood bench. The trial was set up very late in the season in week 37.

Figure 68. Overview of the Belmont ebb and flood bench.

Figure 69.. Close up of a LECA filled lily tray on the ebb and flood bench.

The bench was flooded five times over a 24 hour period and then allowed to completely drain away leaving the moisture just in the LECA pellets.

Results

The nature of the trial and the actual results obtained were not easy to record as traditional data and most of the results are therefore presented as observations on specificationific dates backed up with photographic evidence. Wherever possible the following results tie in with the dates outlined in the materials and methods section.

YEAR 1 (2015)

April 22nd 2015

Overall the column stock plugs and blocks planted on March 27th looked very sick and none could be considered to be growing adequately (Figure 70). This was in stark contrast to the blocked lettuce which were growing away very vigorously and almost ready to be harvested (Figure 71).

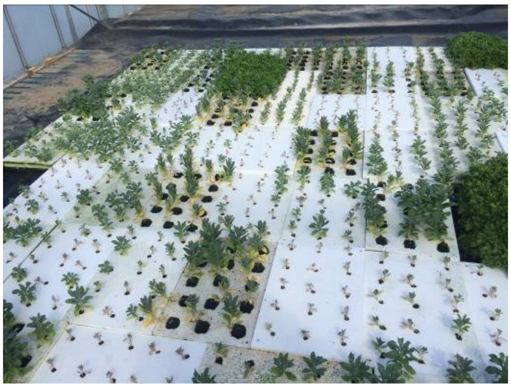

Figure 70. Overall view of the trial (April 27th 2015) showing poor growth of column stocks contrasted with the three lettuce floats.

Figure 71. Growth of the lettuce (April 27th 2015) contrasted with the very poor growth of the column stocks.

In comparison to most of the column stock plugs which were either dead or very sick (Figure 72), the blocks looked more healthy, but they were by no means growing away as would have been expected four weeks after planting (Figure 73).

Figure 72 Poor growth of column stock plugs plants on April 27th 2015.

Figure 73. Growth of column stock blocks on April 27th 2015.

All of the column stock plants (plugs and blocks) had very poor roots which turned brown and in most cases died completely when they grew into the water (Figure 74). It would appear that the block plants looked more healthy than the plugs due to initially having a larger root network to sustain the plants. There was no apparent difference between any of the floats with or without air gaps. This was in stark contrast to the lettuce roots which were vigorous, white and healthy (Figure 75)

Figure 74. Poor root growth of the blocks of column stocks.

Figure 75. Root growth of the lettuce blocks planted at the same time as the stocks in Figure 66.

Most of the blocked stocks were now looking as sick as the plugs (Figure 76) although some floats (especificationially those directly above the return pipe from the pump) were looking healthier and had produced a bud (Figure 77). There were also the odd random healthy plants or two in some of the plug floats despite the poor quality of the other plants around them. No obvious reason could be deduced for these anomalies.

Figure 76. Poor growth of column stocks grown from blocks.

Figure 77. Blocked column stocks showing slightly better growth.

The floats of brassica were growing away vigorously indicating that there was no issue with producing cruciferae in a deep pool hydroponic system (Figure 78). The lettuce floats had also grown vigorously and two of the floats were removed in order to make space around them (Figure 79). The third float was left in place to see if the leaves showed any signs of nutrient deficiency as they matured.

Figure 78. Vigorous growth of the brassica plugs that were planted on April 27th 2015.

Figure 79. Vigorous growth of the lettuce blocks planted on March 27th 2015.

A few of the healthier looking block grown column stock floats with air gaps (planted on March 27th 2015) had by now produced quite strong stems (Figure 80), however the roots were only white and healthy in the air gap, whereas the roots in the water were brown and dying (Figure 81).

Figure 80. One of the healthier stems of block raised column stocks showing poor quality roots.

Figure 81. Close up of the roots showing the white root which developed in the air gap and brown root growing in the water.

None of the changes made to the air gaps on April 27th 2015 had made any difference to the growth of the column stocks. Most had either died or looked very sick, but a few random stems had produced flowering stems randomly scattered throughout the pool with no obvious pattern (Figures 82 and 83). By contrast the statice, asters, lettuce, brassica and Lisianthus continued to grow vigorously with healthy white roots (Figures 84 and 85)

Figure 82. Overall view of the trial at the MG meeting on May 26th 2015.

Figure 83. One of the random healthy stems of stocks from the original planting of March 27th 2015.

Figure 84. Overall view of the trial at the MG meeting on May 26th 2015 showing healthy growth of brassica in the foreground.

Figure 85. Overall view of the trial at the MG meeting on May 26th 2015 showing healthy growth of asters in the foreground.

At the time of clearing the dead and sick plants from the pool, there were no more than 10 stems of stocks that had flowered and produced what were just about marketable stems (Figure 68). The remainder of the poor plants had brown and decaying roots (Figure 87).

Figure 86. View of the pool on June 12th 2015.

Figure 87. Decaying roots of column stock on June 12th 2015.

The roots shown in Figure 87 contrast markedly with the healthy roots and growth of the Lisianthus (Figure 88), aster (Figure 89) and statice (Figure 90).

Figure 88. Lisianthus on June 12th 2015.

Figure 89. Aster ericoides on June 12th 2015.

Figure 90. Statice on June 12th 2015.

Before the pool was cleared and drained, the oxygen level was measured and was found to be very low at 1.7 mg/l (18% saturation).

June 16th 2015

Four days after the Lisianthus were left out of the water for 5 hours while the pond was cleaned, the healthy plants rapidly started to wilt and die (Figure 91). The roots appeared to dissolve in the water and they were surrounded by a milky liquid. This did not happen to any of the other specificationies and at the time of writing this report could not be explained.

Figure 91 Wilted plants on June 16th, 4 days after the pool was cleared and refilled.

July 7th 2015

The first flush of statice (which was planted on May 21st) was harvested (Figures 92 and 93) in order to encourage the production of new stems.

Figure 92. Statice plants before harvesting on July 7th 2015.

Figure 93. Statice plants after harvesting on July 7th 2015.

July 21st

Three weeks after the oxygen concentration was increased by using an aquarium pump and air stones, there was a dramatic improvement in the growth of the plants in the floats directly above the air stone (Figure 94). For the first time during the trial, the column stocks had developed healthy white roots when growing into the water (Figure 95)

Figure 94. Healthy growth of a float of column stocks immediately above an air stone.

Figure 95. Healthy roots of column stocks from the float shown in Figure 86.

However the effect of the extra oxygen concentration rapidly diminished away from the air stone and was not evident two full floats away (Figures 96 and 97). This was very surprising because even though the oxygen level immediately above the air stone was measured at 8.1 mg per litre (81.5% saturation) other areas of the pool were still 4 times higher than the initial levels at around 6.5 mg/l (65% saturation).

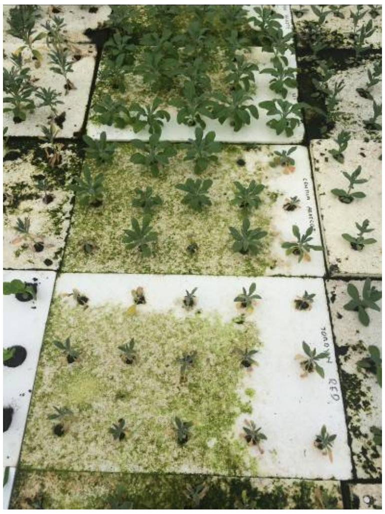

Figure 96. Differences in growth two trays away from the air stone. The float at the top middle of the picture is the one shown in Figures 94 and 95.

Figure 97. A comparison of the float immediately over the air stone and the second float from the air stone i.e. the top and bottom trays of Figure 96.

A number of the apparently healthy plants growing in the floats above the air stone were now showing signs of wilting (Figure 98). Close examination showed that the problem was actually the stem base detaching the root and stems from each other (Figure 99). Samples of the wilting plants were sent to STC plant clinic and *Phytophthora* was identified.

Figure 98. Wilted plants in the floats above the air stones.

Figure 99. Plant showing *Phytophthora* affecting the stem base.

August 29th 2015

After the addition of Subdue to the water, the problem of wilting and stem base rot reduced considerably, however it was not possible to say that it had been eliminated completely owing to infections that would have occurred before the problem was diagnosed. By the end of August the chrysanthemums, asters, statice and lettuce continued to thrive (Figure 100) while the Lisianthus appeared to have stopped growing and was suffering from severe tip burn. The column stock floats above the air stones, while far from being the best quality, were probably growing as well as could be expected for the time of year (Figure 101)

Figure 100. Continued strong grow of lettuce, asters, statice and chrysanthemums.

Figure 101. Column stocks on left showing good growth over air stones. Second row from left is Lisianthus showing poor growth even over air stone.

September 23rd 2015

The Anytime red planted on July 29th (Figure 102) and the Centum cream (Figure 103) planted on July 1st had now produced a number of marketable stems, mainly in the floats over the air stone. These had fallen over owing to lack of support but the fact that any stems of this quality had been produced at this time of year was very surprising to the growers who viewed them.

Figure 102. Marketable stems of Anytime red planted on July 29th.

Figure 103. Marketable stems of Centum Cream planted on July 1st.

November 6th 2015

The shallow pool which had been dosed with the electrolysed water had now produced a number of strong marketable stems (Figure 104) with a strong, healthy and vigorous root structure (Figure 105) whereas the column stocks in the shallow pool without the dosing had either died or looked very sick. The results from the dosed shallow pool did in fact produce some of the strongest stems seen through the whole of the 2015 trial and the quality very much surprised the MG members in early November. However, it must be noted that even in such a shallow depth of water the best growth occurred directly over the air stone where the oxygen concentration was measured at around 8.5 mg/l (high 80's% saturation) whereas away from the air stone in areas of poor growth it was still around 7 mg/l (low 70's% saturation).

Figure 104. The shallow pool dosed with the electrolysed water (on the right) which produced a large number of marketable stems.

Figure 105. Strong healthy roots of the column stocks growing in the shallow pool dosed with electrolysed water.

A number of stems of Centum red from the dosed shallow pool system were harvested and taken to a local packer for vase life testing (Figure 106).

Figure 106. Stems of Centum red harvested from the dosed shallow pool on November 6th 2015.

November 11th 2015

The chrysanthemums and aster ericoides were in full flower by the beginning of November (Figure 107). The quality and stem strength of the chrysanthemums was superb (based on contractor's and growers' expertise) although they would require adequate crop support in a commercial situation (Figure 108).

Figure 107. Chrysanthemum and aster in full flower on November 11th 2015.

Figure 108. Close up of chrysanthemum float on November 11th 2015.

A number of samples of the nutrient solution were analysed by Eurofins (Appendix III) and the results interpreted by Dr Paul Challinor. It is interesting to note that despite numerous breakdowns and issue with the old Heron controller, the nutrient analysis remained very stable and on target, hence demonstrating the substantial buffering effect of a deep pool system. It was only towards the end of the project that the pH started to rise (owing to the acid dosing system irreparably breaking down) hence affecting the nutrient balance.

YEAR 2 (2016)

May 13th 2016

The plants in both the deep pool and shallow pool systems grew away well and the following photos (Figure 109-112) show the growth a month after planting. At this stage there was no real difference in the growth of the floats directly under air stones when compared with the two outside rows of floats.

Figure 109 Healthy and even growth of the stocks in the deep pool one month after planting.

Figure 110 Healthy root growth on the plants in the deep pool one month after planting.

Figure 111 Good growth of floats in one of the shallow pool. Note the superb growth of the lettuce.

Figure 112 Good growth of floats in all three of the shallow pool systems.

By contrast the plants in the aeroponic system looked very poor with weak, chlorotic growth (Figures 113 and 114).

Figure 113 Close up view of an individual plant in one of the aeroponic tubes.

Figure 114 Overview of growth in the aeroponic system.

May 27th 2016

By the end of May the crop in the deep pool system was growing away vigorously and looked like it would need support to keep the crop upright. At this stage growth in the outside floats was starting to look less healthy than in the floats above the air stones.

Figure 115 Close up of deep pool floats after being supported by wires, The plants had budded up well.

Figure 116 Overall view of growth of plants within the deep pool system.

June 13th 2016

By early June the first planting in the deep pool system was ready for harvesting but it was not harvested until the 13th (in order to show to the management group) (Figures 117 and 118). At this stage the differences in growth of plants in the heavily oxygenated areas compared to those in the outside rows was very marked. The further away that the plants were from the air stones the more stunted and chlorotic they were.

Figure 117 Management Group (MG) meeting discussing the results of the first round of the deep and shallow pool system.

Figure 118 Overall view of the deep pool trial just before harvest. Note the very poor growth of the plants in the outside rows.

A full row harvested across all four floats were laid out in order of oxygen concentration gradation. As can be seen in Figures 119 and 120, the plants illustrate the oxygen gradation well, with the plants at the far extremes (i.e. lowest oxygen concentration) being very stunted and chlorotic.

Figure 119 Close up of one end of the scale showing the effect of low water oxygen levels on the growth of the plants.

Figure 120 Overall view of the complete scale of oxygen gradation

The two trays moved to the low oxygen corner of the deep pool on May 14th (Figure 121) contained totally unmarketable plants, whereas the two trays moved from the low oxygen concentration to above the air stones in the main trial were still showing very healthy growth (Figure 122).

Figure 121 Stunted and chlorotic growth of the two floats moved to the low oxygen corner of the deep pool on May 14th 2016.

Figure 122 Healthy growth of the two floats moved from the low oxygen area to the oxygenated area of the deep pool.

The first round of floats in the shallow pool system were not marketable (Figures 123 and 124). The main reason for the poor final development of this first round was most likely due to oxygen levels being too low in the water, hence doubling the number of air stones each shallow pool.

Figure 123 (left) and 124 (right) Views of the shallow pool trial just before clearing out and replanting. Note that the floats of lettuce had been removed a week earlier due to rapid growth.

June 26th 2016

Despite a poor start, the first planting of the aeroponic trial had now produced some reasonable length stems with a good flower (Figure 125). However, the stems did not grow strongly enough to support themselves (as expected) so for this to be a viable commercial system a support system would need to be devised. The plants in the tulip pin trays grew away strongly but differences were starting to emerge in the different trays (Figure 126).

Figure 125 View of the first planting of the aeroponic system showing good quality stems even though they could not support themselves.

Figure 126 View of the tulip pin tray trial two weeks after planting.

July 4th 2016

The plugs transplanted into the 4.5 cm and 5.5 cm net pots as well as the 4 cm Oasis blocks on June 21st 2016 were large enough to transplant into both the deep pool and shallow pool system (Figures 127 and 128).

Figure 127 Net pots and Oasis blocks ready to be transferred to the relevant deep and shallow pool floats.

Figure 128 Oasis blocks and net pots in place in the relevant floats.

July 31st 2016

By late July all of the different systems were growing away well, with poor growth only being evident in the tulip pin trays with the drain plug that retains a few cm of water in the base of the tray. There were however signs of slower growth in some of the floats of net trays and Oasis plugs. Examples of the growth in the different systems are shown below in Figures 129-132.

Figure 129 The second round of the deep pool system in late July

Figure 130 The second planting of the aeroponic system in late July.

Figure 131 Second round of the shallow pool system (with additional oxygenation) almost ready for harvesting at the end of July. The tulip pin tray trial is to the left of the picture.

Figure 132 The effect of retaining a few cm of water in the base of the pin tray. Compare this with the healthy trays in the bottom left hand corner of Figure 124.

August 8th 2016

At the CFC Open Day on August 10th, growers expressed surprise that flowers of this quality could be produced from such a small pot with such little compost. It was felt that if these results could be reproduced on a commercial scale that this system could be used with ebb and flood benches. In contrast the float of these pots planted in the shallow pool had produced poor growth with most of the roots dying once they had been immersed in the water. The only pots to grow well in this float were the two directly above the air stone where the oxygenation was at its greatest (Figure 134) again demonstrating the high oxygen requirement of stocks. Figures 133-136 show the range in growth.

Figure 133 Superb growth of stock plugs transplanted into 9 cm net pots and allowed to grow pot thick in the shallow plant tray.

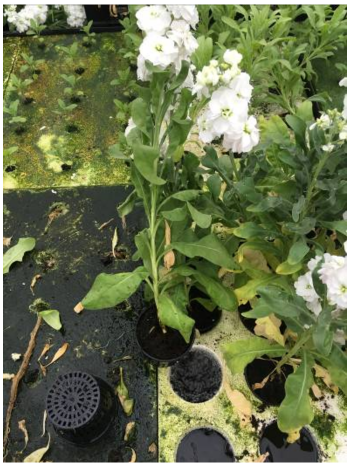

Figure 134 The only pots in the shallow pool that produced a marketable stem were two directly above the air stone.

Figures 135 and 136 The plant on the left was grown in the shallow pool whereas the plant on the right was left pot thick in its original situation growing in a shallow plant tray.

August 30th 2016

Owing to the hot weather in late July and into August, not all of the varieties of stocks in the second planting of the deep pool trial had initiated flowers. Hence only the Anytime and Jordyn were in flower by the time the pool was cleared out at the end of August. As was expected, the quality of those that did flower were not as good as the first round (which were produced during the optimum period for stock production) (Figures 137 and 138). It was also noted that the floats of net pots and Oasis blocks did not perform as well as the floats of direct planted plugs. It would appear the healthy white roots initially produced before the pots were introduced to the pool were killed after being fully immersed in the deep pool. Perhaps these would have performed better if the float had been designed to maintain an air gap and prevent all of the roots being saturated with water.

Figure 137 and 138 The second round of stocks in the deep pool in full flower by the end of August.

September 12th 2016

By mid-September the second planting of Anytime in the vertical aeroponic system was flowering although just like in the deep pool system, the Centum had not initiated a bud (Figures 139 and 140). As was the case with the first planting, this system produced potentially marketable stems but they would have to be supported somehow.

Figure 139 and 140. Flowering stems of Anytime in the aeroponic system in mid-September. Note that the Centum in the left hand tubes have not initiated flower buds.

November 14th 2016

By mid-November all of the tulip pin trays had produced some marketable stems but these were obviously not of the highest quality owing to the lateness of the season.

Figures 141 and **142.** Anytime sea blue in flower in mid-November in the tulip pin trays using extruded clay pellets as the substrate.

YEAR 3 (2017)

J A Collison Trials

The first round of stocks planted in the LECA pellets grew away consistently and flowered in week 16. Good strong stems were produced, but they were not self supporting resulting in bent stems. The following photographs show the crop just before harvest (figure 143 and 144) and at the assessment stage (figure 145 and 146)

Figue 143 EC of 2.0.

Figure 144 EC of 2.5

Figure 145. Photo showing the strong but bent stems owing to not being self supporting

Figure 146 Photo showing good quality flower spikes which more than met the required specification

There was no real visual difference between the performance of the three different EC levels regarding stem length, strength, flowering time and size of flower spike, but the lower EC level (1.5) showed severe nutrient deficiency in the leaves (Figures 147 and 148). This was thought to be iron or manganese deficiency, although this was not confirmed by tissue analysis. No deficiencies were observed at 2.0 and 2.5 EC.

Figure 147 and 148. Photos showing the leaf nutrient deficiency in the 1.5 EC treatment

Table 8 shows the records taken using 20 stems from each system on the 23rd of April 2017. Each stem was weighed and measured before being trimmed to 52 cm and the lower leaves removed (as per the commercial crop) before being weighed again. EC = electrical conductivity

	EC 1.5			**EC 2.0**				**EC 2.5**		
Stem	Total Length	Total Weight	Trimmed Weight	Total Length	Total Weight	Trimmed Weight		Total Length	Total Weight	Trimmed Weight
1	62	86	48	60	98	58		52	102	58
2	52	72	46	63	70	36		60	74	44
3	57	74	42	64	116	52		59	72	46
4	59	68	36	63	94	44		58	90	44
5	62	90	46	63	108	54		59	82	52
6	64	96	46	68	106	44		57	94	48
7	62	84	42	61	97	48		58	118	56
8	63	82	42	56	62	36		59	82	48
9	61	84	46	63	90	42		52	64	42
10	63	82	36	52	62	36		53	64	38
11	61	83	40	55	90	50		55	84	52
12	59	86	46	60	82	47		55	74	46
13	52	62	38	56	86	43		56	82	50
14	59	81	38	59	98	48		52	66	44
15	59	88	46	61	92	42		59	80	48
16	59	80	44	65	86	42		56	68	44
17	61	78	42	59	74	42		56	82	46
18	59	86	46	62	90	46		52	106	56
19	59	68	34	63	94	48		52	106	64
20	58	94	42	61	96	46		52	80	46
Average	**59.55**	**81.2**	**42.3**	**60.7**	**89.55**	**45.2**		**55.6**	**83.5**	**48.6**

Neame Lea trials

The first round of "cold grown" pot and module grown plants at Neame Lea Nursery flowered in week 16 and while they produced weaker and shorter stems than the LECA trial, they were self supporting and the plants did not fall over or produce bent stems. The following photos show the trial just before harvest (Figures 149 and 150). Unfortunately the "warm" crop from the week 2 planting (which flowered 3 weeks earlier) was harvested by the nursery staff before any records could be taken.

Figure 149. Crop of Mathilda cream and Figaro lavender on 19th of April.

Figure 150. Photo showing length of stem and flower spike of Figaro lavender

Table 9 shows the records taken using 20 stems of the week 2 planting of Mathilda and Figaro Lavender on the 19th of April 2017. Each stem was weighed and measured before being trimmed to 52 cm and the lower leaves removed (as per the commercial crop) before being weighed again.

Mathilda cream				Figaro lavender			
	Total length	Total weight	Trimmed weight		Total length	Total weight	Trimmed weight
1	62	48	26		58	55	34
2	62	48	27		60	56	32
3	60	52	34		59	76	45
4	62	58	32		58	75	31
5	62	60	35		59	51	28
6	60	55	31		58	69	36
7	62	58	33		58	53	32
8	62	58	33		60	51	30
9	61	48	29		60	58	30
10	62	52	26		59	47	26
11	62	60	33		67	58	38
12	60	58	34		60	62	33
13	61	51	26		60	79	42
14	59	52	27		61	63	33
15	64	55	29		58	43	24
16	59	42	26		61	63	34
17	62	57	29		58	70	35
18	60	57	29		56	69	39
19	59	56	29		57	43	24
20	60	55	30		60	62	37
Average	**61.05**	**54**	**29.9**		**59.35**	**60.15**	**33.15**

The week 6 “cold” planting of Francesca and the week 10 “warm” planting of Francesca both flowered in week 19 (Figures 152, 153 and 154)

Figure 151. Stage of growth of the “warm” crop grown in modules (photo taken in week 16)

Figure 152. “Cold” crop of Francesca just before harvest in week 19.

The “cold” grown crop produced a much stronger and thicker stem than the “warm” crop flowering at the same time (Figures 153 and 154).

Figure 153.Two stems of “cold” grown crops on the left and “warm” grown on the right.

Figure 154. Close up of stems of “cold” grown crop on the left and “warm” grown on the right.

Table 10 shows the records taken using 20 stems of the week 6 cold planting of Francesca and the week 10 warm planting of Francesca on 14th May 2017. Each stem was weighed and measured before being trimmed to 52 cm and the lower leaves removed (as per the commercial crop) before being weighed again.

Week 6 cold crop					Week 10 warm crop		
	Total length	Total wt	Trimmed wt		Total length	Total wt	Trimmed wt
1	62	92	53		58	63	39
2	62	90	48		54	58	36
3	52	87	51		54	62	42
4	55	81	51		55	52	35
5	52	68	41		52	52	32
6	52	85	42		52	53	38
7	54	69	44		55	47	33
8	55	66	41		56	61	36
9	52	86	46		56	50	32
10	52	82	48		52	55	34
11	62	69	39		52	45	34
12	52	83	49		52	66	29
13	52	89	51		54	53	32
14	52	68	42		52	46	31
15	52	72	43		54	50	34
16	54	65	37		59	57	40
17	55	84	47		56	54	32
18	52	81	52		52	46	26
19	52	74	52		52	55	36
20	52	81	47		54	49	32
Average	**54.15**	**78.6**	**46.2**		**54.05**	**53.7**	**34.15**

YEAR 4 (2018)

J A Collison trials

All three of the LECA units at J A Collison grew away well and produced a potentially marketable crop had it not have been for stem bending, as seen in previous years. The following photos show the crop just before harvest and assessment (Figures 155 and 156).

Figure 155 SensiBloom at EC of 2.5

Figure 156. Kristalon Blue at EC of 2.5

Figures 157 and 158 show examples of the harvested stem at the assessment stage.

Figure 157 Strong but bent stems owing to not being self supporting

Figure 158 Good quality flower spikes which more than met the required specification except for the bent stems.

Table 11 shows the records taken using 20 stems from each system on the 9th of May 2018. Each stem was weighed and measured before being trimmed to 52 cm and the lower leaves removed (as per the commercial crop) before being weighed again

	Total Length	Total Weight	Trimmed Weight		Total Length	Total Weight	Trimmed Weight		Total Length	Total Weight	Trimmed Weight
1	83	56	49		62	58	32		48	58	27
2	64	55	37		63	55	41		48	57	25
3	66	58	36		53	58	27		63	60	34
4	49	52	31		67	56	37		64	61	42
5	46	54	29		51	62	27		50	52	32
6	56	54	29		48	57	26		86	58	31
7	69	62	46		89	60	47		75	61	37
8	74	64	44		58	62	29		70	60	34
9	74	64	44		82	62	47		57	55	35
10	67	61	41		77	61	46		89	62	52
11	59	62	34		71	58	38		82	61	42
12	84	66	46		78	58	25		87	63	44
13	82	66	42		62	56	36		67	55	32
14	51	56	32		69	57	37		49	54	26
15	41	52	25		63	61	33		49	54	29
16	58	57	34		52	58	30		58	54	29
17	53	60	30		55	58	34		63	52	35
18	67	56	37		63	57	37		64	57	36
19	54	52	29		62	58	34		52	62	28
20	62	52	37		68	54	42		60	54	28
Average	**62.95**	**57.95**	**36.6**		**64.65**	**58.3**	**35.25**		**64.05**	**57.5**	**33.9**

Belmont Nursery trials

As this trial was set up so late, it was abandoned before it produced any flowers so no measurements could be taken. However by mid-November it was clear that as with the J A Collison LECA system, growing in LECA filled trays on an ebb and flood system can produce strong healthy stems. Again, these were not self-supporting and would have led to unmarketable bent stems if the trial had been planted early enough to allow the stems to flower. Photos of the trial just before it was abandoned in mid-November are shown in Figures 159 and 160.

Figure 159. Close up of a tray in week 45 showing healthy foliage.

Figure 160. A tray in week 45 showing bent stems owing to not being self supporting.

Discussion

FIRST YEAR (2015)

The 2015 trial has shown that a simple deep pool hydroponics system has the potential to produce a range of cut flowers to a commercial standard. In these trials statice, aster ericoides and chrysanthemums grew adequately and all produced what would have been a marketable stem had adequate crop supports have been in place. Two of these specificationies, asters and statice grew in the pool for the most of the trial (from April to November) with no issues with the health of the roots. The statice cropped consistently from early July through to being removed from the pool in mid-November.

Lettuce was used as a "check" specificationies throughout the trial because its performance in such a system is well understood. In all cases the lettuce grew vigorously with a mass of healthy white roots and was ready for harvesting within a few weeks. This clearly demonstrated that there was nothing fundamentally wrong with the deep pool system that was being used for the experiment.

The performance of the Lisianthus was less consistent and difficult to fully explain. The initial planting of April 27th 2015 grew away well and produced healthy white roots up until being removed from the water for approximately 5 hours while the pool was emptied, cleaned and refilled on June 12th 2015. Four days after being returned to the pool the Lisianthus began to wilt and the roots appeared to dissolve producing a mass of milky white liquid in the area around the roots. The reasons behind this are not clear, but perhaps the delicate root hairs were destroyed while out of the water. However this was not an issue with the statice or asters. The second planting of Lisianthus also failed to perform as expected and never grew more than 15 to 20cms tall and suffered from severe tip scorching. This is a crop that has been trialled in Holland and been shown to grow in "water" so the results in this trial are surprising. It is possible that the subsequent rise of pH owing to issues with the acid dosing system could have contributed to some of the growth problems observed.

The main objective of the 2015 trial was to determine if column stocks could be successfully grown in a deep pool hydroponic system. As can be seen from the results, the process of determining ideal conditions for column stock production was difficult and protracted. A number of variables were explored, and as can clearly be seen by the photographic record in the results section, the only variable that consistently improved the growth of the column stocks was the addition of increased oxygen, but even then only when it was around or higher than 8 mg/l (80% saturation). Before starting the trial it had been assumed that the nutrient recipe was one of the most important factors to consider, but the results to date indicate that for column stocks the oxygen concentration in the water is by far the most important issue.

As perhaps expected, root and stem diseases are a potential issue with a solution hydroponic system, hence the need to treat the trial pool with Subdue to control *Phytophthora.* However, it is worth noting that because of the location of the trial facility (it shared a main access with an adjoining commercial glasshouse where intensive cropping was undertaken in the soil), it was not possible to apply a hygiene regime that was as high as would be the case in a commercial nursery dedicated to just hydroponics.

The additional experiment looking at the use of electrolysed water to control alga and diseases produced some interesting results in that the treatment resulted in some of the best stems of the whole trial. This not only demonstrates that the treatment has real potential but it also opens up the possibility of stock production in a shallow pool system, something that had not been considered at the time of submitting the initial proposal to the AHDB. However, at this stage caution must be exercised in the interpretation of these results owing to it being a single un-replicated and unrepeated trial. Further work was required confirm the provisional 2015 findings.

While the positive results of increasing the oxygen concentration seemed to be consistent during the 2015 trial, it must be pointed out that because of the lateness in the year, it was not possible to produce a full crop of stocks which had been subject to both high levels of oxygen in water dosed with Subdue from day 1 of planting the plugs. As with the shallow pool trial, further work was required to confirm and replicate the 2015 findings.

As a closing point of discussion the following pictures (Figures 161 and 162) show the results of the first and final plantings of column stocks in 2015 trial. This clearly demonstrates the progress that has been made in meeting the objectives of this project.

Figure 161. First planting of column stocks (27th March 2015) showing poor growth on June 1st 2015. The lettuce is the furthest float and the brassica the closest float.

Figure 162. Final crop of column stocks (29th July 2015) produced in the dosed shallow pool showing marketable stems on November 6th 2015.

SECOND YEAR (2016)

Initially, the main aim of the second year trial in 2016 was to concentrate on column stocks in both shallow and deep pool systems with a view to confirming and replicating the year 1 (2015) findings, especificationially the high oxygen requirement and the need for fungicides to be added to the deep pool solution.

A number of different elements of the 2016 trial verified the 2015 findings that column stocks have a demand for high oxygen levels in the deep and shallow pool solutions. These include the effect on growth of a high to low oxygen gradation, the effect of moving healthy trays from an area of high to low oxygen concentration, or low to high, and the need to double the number of air stones in the shallow pool system to improve the quality of second round planting. In order to move from a small trial to a commercial scale system an engineering solution would need to be developed to adequately oxygenate the water to an appropriate level, and this will likely be more difficult with a shallow pool than a deep pool system. It may also be possible to redesign the floats for example, to have an air gap when using plug grown in net pots.

It was also clear from both the 2015 and 2016 trials that the plants need to be supported and if the floats are to be moved around the system from planting to harvest (as is the case with deep pool lettuce production) the support system would probably need to be an integral part of each individual float.

All of these engineering solutions are beyond the scope of the current project and would probably need to be undertaken by individual growers who wish to now build on these trial results and to develop their own system.

The addition of Subdue and Paraat to the deep pool water seemed to keep oomycete diseases under control during the 2016 trial. It would appear that some form of sterilisation technique or pesticides will need to be incorporated into any larger scale commercial system in order to control root and stem diseases.

The 2016 trial programme also enabled two additional systems to be investigated: a vertical aeroponic system and extruded clay pellets as a substrate in tulip pin trays. The aeroponic system produced potentially marketable stems but for the system to be taken up commercially, a support system would need to be devised and a careful assessment of the economics of production would need to be undertaken. The tulip pin trays filled with a clay pellet substrate showed real potential but needed to be investigated further in order to assess its full potential.

Perhaps the most surprising result of the 2016 trials was the fact that high quality (and apparently self-supporting) stems of stocks were produced in a 9 cm net pot using what can only be described as a "Heath Robinson" ebb and flood system. This was a result that warranted further investigation on a commercial ebb and flood system.

THIRD YEAR (2017)

Both of the systems investigated in these trials produced potentially marketable stems but both had issues that need to be addressed before they can be grown on a commercial scale.

The LECA system produced very strong stems with a column length longer than the minimum supermarket specification (45-52 cm) but unfortunately as per last year's trial, the plants were not self-supporting and hence produced curved stems. There were no visual differences in stem strength and length between the three EC levels and the records taken from the 20 random stems only showed small differences, e.g. an average trimmed stem weight of 42.7 g for an EC of 1.5, 45.5 g for an EC of 2.0, and 48.2 g for an EC of 2.5. The lower EC level did show signs of nutrient deficiency symptoms, which would have made the crop unmarketable, whereas no deficiency symptoms were evident at the highest EC level. Therefore this would be the level to aim for in a commercial crop.

The module system at Neame Lea produced a self supporting crop but with an overall lower stem weight and shorter stem length for the early planted crop. However at a density of 107 per sq/m this is considerably more than the normal commercial planting of 64 per sq/m so it is perhaps not surprising that a lower stem weight was produced. But it must be noted the main specification for stocks is based on length (45-52 cm depending on time of year and the retailer concerned), and spike length (12-15 cm) this crop did in fact meet this specification. If the spacing was decreased it is likely that stronger stems would be produced. Since this trial was undertaken in 2017, a commercial crop of column stock has in fact been produced using this system in 2018 confirming that it is a viable production technique.

The Neame Lea trial also clearly demonstrated that heavier and better quality stems can be produced by growing column stocks in a colder environment. The week 6 cold crop of Francesca flowered in week 19 and produced an average stem weight of 46.2 g. The warm crop of Francesca also flowered in week 19 but produced a lower average stem strength of 34.2 g. The weights obtained in the colder environment were in fact comparable with those in the LECA trial, which was grown at similar temperatures.

The value of a column stock crop would not on its own justify the installation of an ebb and flood system but is applicable to existing systems (perhaps being used for tulips or bedding) were the production of stocks would fit a production window when the system was not being fully used by the other crops. In such a situation it was estimated by the growers undertaking these trials that the main extra cost of using a module system, i.e. the growing medium, was offset by not having to steam the soil as would be the case in a normal soil-based production system. There could also be labour saving costs in the pot system assuming the nursery has an automated potting system which can transplant the plugs into the module.

FOURTH YEAR (2018)

The 2018 grower trials mainly confirmed the earlier findings: growing stocks in LECA pellets will produce stems that tend to exceed the market specification in terms of weight, strength of stem and length of both stem and flower spike. However, they are not self supporting in such a system, leading to bent and curved stems rendering them unmarketable. Hence as reported after the 2017 trial, this technique is unlikely to be taken up commercially until an engineering solution can be found to provide some form of crop support. Because of this, the feedback from the industry is that no further AHDB funded work is required to investigate this technique and it is now for individual businesses to decide if they want to develop it along with their own solutions to the support issues.

In all of the trials, the LECA substrate only works successfully where the water is allowed to completely drain away after flooding and the moisture is therefore held within the LECA pellets with no reservoir of water in the base of the container.

Conclusions

- Deep pool hydroponics has the potential to be used for growing a wide range of cut flowers.
- Column stock production is possible in a deep pool system but they require very high oxygen concentration levels in the water.
- Additional engineering solutions would be required to design a bespoke float that would both maximise the oxygen potential of the solution (e.g. an appropriate air gap) and also have a self-contained support system to prevent the stems from falling over.
- The additional trial looking at shallow pool hydroponics has demonstrated that it may be a feasible option for column stock production if an engineering solution could be found to adequately oxygenate the water.
- Vertical aeroponic systems could be used for the production of column stocks but a support system would need to be devised and the economics of production would need to be further evaluated.
- Trials on a commercial nursery with ebb and flood benching have shown that it is possible to produce stocks in either packs or small pots but as would be expected the stem weight achieved is to a certain extent dependent on the size of the module used and associated density of the crop. This production system is now being used commercially within the industry.
- Further trials on growers’ holdings have demonstrated that it is possible to produce good quality stems of stocks (ie strong, long and with a good spike length) using a LECA substrate but that the crop is not self supporting in such a system leading to bent and curved stems. Therefore until an engineering solution can be found to overcome this problem of crop support, this technique is unlikely to be adopted by the industry.

Knowledge and Technology Transfer

The main KT actions were ongoing posts on the blog of the Cut Flower Centre website, an Open Day on 5th August 2015 and 10th August 2016 in conjunction with the CFC annual

Open Days, a 3 page article in the December 2015 / January 2016 issue of the AHDB Grower and a 1 page article in the September 2016 AHDB Grower.

Appendices

Appendix I Nutrient analysis of reservoir water on 17th February 2015

Appendix II Nutrient analysis of mains water on 20th February 2015

Appendix III Various analyses of the pool water throughout the period of the trial.

Appendix I Nutrient analysis of reservoir (rain) water on 17th February 2015

eurofins

Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number None Supplied
AFA Number 02347153

AR-15-UD-061800-01

Reported on 20/02/2015
Reported by Sarah Smith, Analytical Services Manager

Page 1 of 2

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45000316	Received on	17/02/2015
Your sample reference	Water	Your sample code	P Collison Rainwater

	Sample Result				Optimum Values			
pH	6.7				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	135	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<1	mg/l	<0.07	mmol/l	0	2	> 10	As low as possible
Nitrate-N	4.79	mg/l	0.34	mmol/l	150	250	> 300	
Phosphorus	<1	mg/l	<0.03	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	0.726	mg/l	0.02	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	24.3	mg/l	0.61	mmol/l	150	250	>300	
Magnesium	0.652	mg/l	0.03	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	4.08	mg/l	0.18	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	14.0	mg/l	0.40	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	2.22	mg/l	0.07	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	<0.02	mg/l	<0.36	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	<0.02	mg/l	<0.36	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	<0.05	mg/l	<4.55	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.08	mg/l	1.18	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	<0.01	mg/l	<0.16	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	0.15				> 3.0	2.0	< 1.6	
K:Ca Ratio	0.03				> 3.0	2.0	< 1.6	
K:Mg Ratio	1.11				> 8.0	6.0	< 5.0	
K:Na Ratio	0.18				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	0.052				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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Appendix II Nutrient analysis of mains water on 20th February 2015

eurofins

Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number	None Supplied
AFA Number	02347153

AR-15-UD-061801-01

Reported on	20/02/2015
Reported by	Sarah Smith, Analytical Services Manager

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45000317	Received on	17/02/2015
Your sample reference	Water	Your sample code	P Collison Mains

	Sample Result				Optimum Values			
pH	6.7				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	680	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<1	mg/l	<0.07	mmol/l	0	2	> 10	As low as possible
Nitrate-N	8.80	mg/l	0.63	mmol/l	150	250	> 300	
Phosphorus	1.45	mg/l	0.05	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	2.72	mg/l	0.07	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	139	mg/l	3.47	mmol/l	150	250	>300	
Magnesium	2.51	mg/l	0.10	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	19.0	mg/l	0.83	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	76.6	mg/l	2.16	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	9.36	mg/l	0.29	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	<0.02	mg/l	<0.36	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	<0.02	mg/l	<0.36	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	<0.05	mg/l	<4.55	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	<0.02	mg/l	<0.31	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.01	mg/l	0.22	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	0.31				> 3.0	2.0	< 1.6	
K:Ca Ratio	0.02				> 3.0	2.0	< 1.6	
K:Mg Ratio	1.08				> 8.0	6.0	< 5.0	
K:Na Ratio	0.14				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	0.036				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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Appendix III Various analyses of the pool water throughout the period of the trial.

eurofins

Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number None Supplied

AR-15-UD-130523-01

Reported on 14/04/2015
Reported by Tracie Elwell, Customer Services Advisor

Page 1 of 2

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45000797	Received on	10/04/2015
Your sample reference	Hydroponics	Your sample code	P Collison Next To Tank

	Sample Result				Optimum Values			
pH	6.0				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2010	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	5.44	mg/l	0.39	mmol/l	0	2	> 10	As low as possible
Nitrate-N	126	mg/l	9.00	mmol/l	150	250	> 300	
Phosphorus	90.7	mg/l	2.93	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	392	mg/l	10.05	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	108	mg/l	2.71	mmol/l	150	250	>300	
Magnesium	32.3	mg/l	1.35	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	5.98	mg/l	0.26	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	92.8	mg/l	2.61	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	46.4	mg/l	1.45	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.56	mg/l	27.83	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	1.00	mg/l	18.17	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	1.15	mg/l	104.13	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.30	mg/l	4.67	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.09	mg/l	1.43	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	2.98				> 3.0	2.0	< 1.6	
K:Ca Ratio	3.63				> 3.0	2.0	< 1.6	
K:Mg Ratio	12.14				> 8.0	6.0	< 5.0	
K:Na Ratio	66				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	4.2				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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eurofins

Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number: None Supplied

AR-15-UD-130524-01

Reported on: 14/04/2015
Reported by: Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45000798	Received on	10/04/2015
Your sample reference	Hydroponics; P Collison Far Corner of Tank	Your sample code	P Collison Far Corner of Tank

	Sample Result				Optimum Values			
pH	5.9				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2000	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	5.29	mg/l	0.38	mmol/l	0	2	> 10	As low as possible
Nitrate-N	133	mg/l	9.47	mmol/l	150	250	> 300	
Phosphorus	90.4	mg/l	2.92	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	426	mg/l	10.91	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	108	mg/l	2.70	mmol/l	150	250	>300	
Magnesium	32.2	mg/l	1.34	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	6.78	mg/l	0.29	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	93.9	mg/l	2.64	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	46.4	mg/l	1.45	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.55	mg/l	27.60	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	1.00	mg/l	18.12	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	1.14	mg/l	104.03	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.30	mg/l	4.55	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.09	mg/l	1.39	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	3.08				> 3.0	2.0	< 1.6	
K:Ca Ratio	3.94				> 3.0	2.0	< 1.6	
K:Mg Ratio	13.23				> 8.0	6.0	< 5.0	
K:Na Ratio	63				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	4.5				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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eurofins

Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number	None Supplied
AFA Number	02347159

AR-15-UD-182312-01

Reported on	27/05/2015
Reported by	Sarah Smith, Analytical Services Manager

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45001072	Received on	22/05/2015
Your sample reference	Hydroponic; P Collison	Your sample code	Main Production Tank

	Sample Result				Optimum Values			
pH	5.8				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2210	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	2.74	mg/l	0.20	mmol/l	0	2	> 10	As low as possible
Nitrate-N	179	mg/l	12.75	mmol/l	150	250	> 300	
Phosphorus	74.3	mg/l	2.40	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	348	mg/l	8.93	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	194	mg/l	4.84	mmol/l	150	250	>300	
Magnesium	34.1	mg/l	1.42	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	15.0	mg/l	0.65	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	101	mg/l	2.84	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	52.8	mg/l	1.65	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.17	mg/l	20.93	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	0.97	mg/l	17.55	µmol/l	< 0.4	0.5-0.8	> 1.0***	***Toxicity risk higher
Boron	1.01	mg/l	91.80	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.29	mg/l	4.47	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.07	mg/l	1.06	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.91				> 3.0	2.0	< 1.6	
K:Ca Ratio	1.79				> 3.0	2.0	< 1.6	
K:Mg Ratio	10.21				> 8.0	6.0	< 5.0	
K:Na Ratio	23				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	3.4				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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Paul Challinor
May Barn Horticultural Consultancy Limited
May Barn
Poplars Farm
French Lane
Baddington
Nantwich
Cheshire
CW5 8AL

PO Number 02347161; Paul Challinor
AFA Number 02347161

AR-15-UD-250069-01

Reported on 21/07/2015
Reported by Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45001460	Received on	16/07/2015
Your sample reference	Hydroponics: Perch Holme NRY. Hydroponic Pond	Your sample code	Perch Holme NRY

	Sample Result				Optimum Values			
pH	6.7				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2360	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	0.142	mg/l	0.01	mmol/l	0	2	> 10	As low as possible
Nitrate-N	176	mg/l	12.58	mmol/l	150	250	> 300	
Phosphorus	17.6	mg/l	0.57	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	331	mg/l	8.50	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	193	mg/l	4.82	mmol/l	150	250	>300	
Magnesium	39.6	mg/l	1.65	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	26.6	mg/l	1.16	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	51.5	mg/l	1.45	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	66.2	mg/l	2.07	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	2.17	mg/l	38.70	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	0.49	mg/l	8.97	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	0.75	mg/l	68.40	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.38	mg/l	5.83	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.07	mg/l	1.05	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.88				> 3.0	2.0	< 1.6	
K:Ca Ratio	1.72				> 3.0	2.0	< 1.6	
K:Mg Ratio	8.36				> 8.0	6.0	< 5.0	
K:Na Ratio	12				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	6.4				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

UKAS 0342

eurofins

Lyndon Mason
Lyndon Mason
The Old School House, School Road,
Marshland St James
Wisbech, Cambs
GB
PE14 8JS

PO Number 33482

AR-15-UD-396522-01

Reported on 19/11/2015
Reported by Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45002125	Received on	19/11/2015
Your sample reference	Water dample	Your sample code	LRM Horticultural Services Trial Tanl

	Sample Result				Optimum Values			
pH	7.2				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2940	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<0.05	mg/l	<0.00	mmol/l	0	2	> 10	As low as possible
Nitrate-N	228	mg/l	16.26	mmol/l	150	250	> 300	
Phosphorus	1.93	mg/l	0.06	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	374	mg/l	9.58	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	229	mg/l	5.72	mmol/l	150	250	>300	
Magnesium	70.4	mg/l	2.93	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	49.7	mg/l	2.16	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	121	mg/l	3.40	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	97.8	mg/l	3.06	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.83	mg/l	32.75	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	0.04	mg/l	0.67	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	1.01	mg/l	91.83	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.75	mg/l	11.61	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.17	mg/l	2.72	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.64				> 3.0	2.0	< 1.6	
K:Ca Ratio	1.63				> 3.0	2.0	< 1.6	
K:Mg Ratio	5.31				> 8.0	6.0	< 5.0	
K:Na Ratio	7.5				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	3.1				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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0342

eurofins

Lyndon Mason
Lyndon Mason
The Old School House, School Road,
Marshland St James
Wisbech, Cambs
GB
PE14 8JS

PO Number 33482

AR-15-UD-396523-01

Reported on 19/11/2015
Reported by Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45002126	Received on	19/11/2015
Your sample reference	Water	Your sample code	LRM Horticultural Services Tank 2 af

	Sample Result				Optimum Values			
pH	8.1				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	3070	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<0.05	mg/l	<0.00	mmol/l	0	2	> 10	As low as possible
Nitrate-N	232	mg/l	16.60	mmol/l	150	250	> 300	
Phosphorus	3.11	mg/l	0.10	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	408	mg/l	10.47	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	225	mg/l	5.62	mmol/l	150	250	>300	
Magnesium	72.8	mg/l	3.04	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	54.0	mg/l	2.35	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	130	mg/l	3.66	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	102	mg/l	3.20	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.70	mg/l	30.35	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	<0.02	mg/l	<0.36	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	1.08	mg/l	98.31	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.82	mg/l	12.63	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.21	mg/l	3.27	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.76				> 3.0	2.0	< 1.6	
K:Ca Ratio	1.81				> 3.0	2.0	< 1.6	
K:Mg Ratio	5.60				> 8.0	6.0	< 5.0	
K:Na Ratio	7.6				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	3.1				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

UKAS 0342

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Lyndon Mason
The Old School House, School Road,
Marshland St James
Wisbech, Cambs
GB
PE14 8JS

PO Number 33482

AR-15-UD-396524-01

Reported on 19/11/2015
Reported by Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45002127	Received on	19/11/2015
Your sample reference	NFT	Your sample code	LRM Horticultural Services Main Tan

	Sample Result				Optimum Values			
pH	7.1				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2240	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<0.05	mg/l	<0.00	mmol/l	0	2	> 10	As low as possible
Nitrate-N	185	mg/l	13.20	mmol/l	150	250	> 300	
Phosphorus	8.77	mg/l	0.28	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	294	mg/l	7.53	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	177	mg/l	4.42	mmol/l	150	250	>300	
Magnesium	41.0	mg/l	1.71	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	28.4	mg/l	1.23	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	68.2	mg/l	1.92	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	66.4	mg/l	2.08	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	0.81	mg/l	14.52	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	<0.02	mg/l	<0.36	µmol/l	< 0.4	0.5-0.8	> 1.0***	***Toxicity risk higher
Boron	0.64	mg/l	58.28	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.38	mg/l	5.91	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.15	mg/l	2.33	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.59				> 3.0	2.0	< 1.6	
K:Ca Ratio	1.66				> 3.0	2.0	< 1.6	
K:Mg Ratio	7.17				> 8.0	6.0	< 5.0	
K:Na Ratio	10				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	4.3				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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The Old School House, School Road,
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Wisbech, Cambs
GB
PE14 8JS

PO Number 33482

AR-15-UD-396525-01

Reported on 19/11/2015
Reported by Tracie Elwell, Customer Services Advisor

Hydroponics Analysis Report (Tomato)

Sample number	400-2015-45002128	Received on	19/11/2015
Your sample reference	Water	Your sample code	LRM Horticultural Services Tank 2

	Sample Result				Optimum Values			
pH	7.9				< 5.5	6.0	>6.5	Target range: 5.8-6.2
Conductivity at 20°C	2950	µS/cm			< 2,500	4,000	> 6,000*	*Early season growth control
Major Nutrients								
Ammonium-N	<0.05	mg/l	<0.00	mmol/l	0	2	> 10	As low as possible
Nitrate-N	240	mg/l	17.16	mmol/l	150	250	> 300	
Phosphorus	3.57	mg/l	0.12	mmol/l	20	30-40	> 50**	**Induced Zn+Cu deficiency likely
Potassium	411	mg/l	10.54	mmol/l	< 400	500	1,000	Toxicity: rare
Calcium	202	mg/l	5.06	mmol/l	150	250	>300	
Magnesium	67.3	mg/l	2.81	mmol/l	< 65	80	> 100	High K inhibits Mg absorption
Undesirable Ions								
Sodium	48.2	mg/l	2.10	mmol/l	< 100	200	> 400	High Na inhibits uptake of K, Ca, Mg
Chloride	117	mg/l	3.31	mmol/l	< 100	200	> 400*	*Early season growth control
Sulphur	104	mg/l	3.25	mmol/l	< 50	100	> 200	
Trace Nutrients								
Iron	1.57	mg/l	28.00	µmol/l	< 2.0	3.0-4.0	> 5.0	
Manganese	<0.02	mg/l	<0.36	µmol/l	< 0.4	0.5-0.6	> 1.0***	***Toxicity risk higher
Boron	0.94	mg/l	85.43	µmol/l	< 0.3	0.4-0.6	> 1.0	
Zinc	0.84	mg/l	12.96	µmol/l	< 0.5	1.0	> 1.5	Link with P and Mn
Copper	0.17	mg/l	2.66	µmol/l	< 0.05	0.1	> 0.2	
Ratios								
K:N Ratio	1.71				> 3.0	2.0	< 1.6	
K:Ca Ratio	2.03				> 3.0	2.0	< 1.6	
K:Mg Ratio	6.11				> 8.0	6.0	< 5.0	
K:Na Ratio	8.5				> 5.0	2.5	< 1.25	Important in recirc.
K:Cl Ratio	3.5				> 5.0	2.5	< 1.25	Important in recirc.
Other								

Key to interpretation

- Green: At or near optimum concentration
- Orange: Likely to result in nutrient deficiency
- Red: Likely to result in plant damage

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