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AUTHENTICATION

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

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GROWER SUMMARY

Headline

- Coir, perlite and rockwool substrates represent lower risk, transitional production systems, when moving towards protected cut flower hydroponics direct from soil culture.
- More advanced nutrient film technique (NFT) and deep water culture (DWC) could be used once growers are fully attuned to the control needed for such systems.
- However, an investment in accurate nutrient dosing equipment and also computerised pH and EC monitoring is essential for success, regardless of the chosen hydroponics system.
- The design of the hydroponic system should also allow for the future requirement to capture and recirculate all drain water created after irrigation of the crop.

Background

This report reviews information on hydroponics, the science of growing plants without soil, in relation to the production of cut flower crops. In addition, the suitability of currently available hydroponic systems for the intensive production of cut flower crops is also discussed.

Many crops grown intensively over a long season of production, for example UK tomatoes, cucumbers and sweet peppers, have been cultured in a range of hydroponic systems for over 40 years.

The main decision parameters involved in using hydroponics for these crops included the need for improved control over plant growth, leading to higher yields and better marketable quality. In addition, added control over attack by plant pathogens was a further driver towards the use of hydroponics.

The use of soilless cultivation on inorganic substrates is one of the most efficient alternatives to soil sterilisation, since it provides a pathogen-free root environment at planting.

The need to consider hydroponics in cut flowers has been highlighted by the appalling growing conditions of 2012, which led to a large amount of crop loss in certain sectors of the industry, due to disease. This was especially true of column stocks, with some growers losing up to 25% of their crop. A number of leading stock growers have therefore been instrumental in the development of this project.

Summary

In commercial horticultural crop production, the move away from soil in the 1970s to peat-based systems was stimulated by the need to control problems with soil pests, diseases and nutritional imbalances.

In peat systems, practical problems with water content, water availability and nutrient balance limited its application to certain crops, such as tomatoes. All peat systems require a constant supply of nutrients, either in the form of a slow-release fertiliser or as liquid feeds. Depending on the composition and chemical stability of the background water, nutrient imbalances may quickly occur.

Practical experiences on Jersey with the use of peat bags for the production of spray carnations and pinks highlighted problems with variable moisture availability and also susceptibility of the plants to diseases, such as *Fusarium* species.

Research completed at the States of Jersey Department of Agriculture and Fisheries, Howard Davis Farm glasshouse unit, identified several useful alternative substrates, such as pumice, clinoptilolite zeolite, nutrient-loaded clinoptilolite zeolite, perlite, polyurethane foam and products made from forestry residues.

Most of the active research on hydroponic systems took place over the period 1989 until 1998.

The introduction of rockwool (stonewool), as a plant growth substrate in the early 1970s, revolutionised the crop production industry worldwide. Rockwool has been successfully used for long-season production of roses for cut flowers, both in Holland and Guernsey.

Coir is a useful peat replacement material and its popularity as a substrate in UK glasshouse crop production is now increasing.

Using column stocks as an example, control of *Fusarium* species in the soil has become increasingly difficult over the last ten years, resulting in reduced yields and variable flower quality (Figure 1). In the absence of suitable chemical controls, the reliance on sheet steaming has increased in recent years. However, due to high energy and labour costs, coupled with variable results and negative impacts on soil structural and biological parameters, growers would now like to move away from steaming and towards the use of hydroponics.

Therefore, following continued problems with disease control in soil-grown crops, there is renewed interest in hydroponics and this has resulted in small-scale trials using coir and also a modified form of nutrient film technique (NFT) known as deep water culture (DWC),

or deep flow technique (DFT). Coir is one example of **substrate hydroponics**. In contrast, NFT and DWC are two examples of **solution hydroponics**.

Deep or direct water culture is a hydroponic method of plant production by means of suspending the plant roots in a solution of nutrient-rich, oxygenated water. Trials on DWC have involved containers, with plants suspended above the water reservoir on a sheet of polystyrene, for example.

Figure 1. *Fusarium* species in soil grown stocks

Hydroponic systems allow plant growth characteristics to be very carefully controlled. During the crop establishment period, for example, the moisture content of substrate systems may be decreased to encourage root development. As most substrate hydroponic systems require a constant supply of nutrients, the liquid feeding regime may be varied, to encourage vegetative growth., The fertigation strategy may then be further adjusted, in order to support the development of flowers and to ensure a consistent flower product and attendant vase life characteristics.

Investment in accurate nutrient dosing equipment is essential to ensure that the irrigation and liquid feeding regime is carefully controlled. In addition, accurate measurement and adjustment of both pH and EC of the applied feed is essential to ensure success in hydroponics.

In terms of solution hydroponics, general interest in NFT decreased for a number of reasons, including the high initial capital cost, system failures, nutritional problems and plant losses through root disease. Specific issues with acid overdosing, low oxygen concentrations in the NFT solution and accumulation of unwanted ions (such as sodium, chloride and sulphate) increased the risk of crop loss.

These highlighted risks also exist for production of crops in any nutrient recirculation system, including all types of solution or substrate hydroponics.

Therefore, further research is required to reduce these risks to a minimum and ensure that reliable production may be maintained. In addition, growers face the situation where drainwater volumes must be reduced and safely managed in the future.

Tables 1 and 2 summarise the current position with regard to UK experience with each main substrate and solution hydroponic system. As may be clearly seen, there exists more information and knowledge of the management of substrate systems based on coir and rockwool. In terms of solution hydroponic systems, there is more UK growing experience with nutrient film technique and much less involvement with Deep Water Culture systems at present.

These tables also indicate where future research and development should be targeted, in order to provide growers with a more robust knowledge base going forward. For example, although there is interest in the use of Deep Water Culture systems for the production of UK cut flowers, there is limited European experience available at the moment.

In summary, it is proposed that the suitability of the following substrate systems should be determined for future UK hydroponic flower production systems: coir, forestry residues, pumice and rockwool (stonewool). In addition, the solution hydroponic systems offered by Botman Hydroponics B.V. and Cultivation Systems B.V. should be further explored for cut flower production and thoroughly tested under UK protected crop conditions.

Table 1. Summary of substrate hydroponic system characteristics

Substrate System	UK System Experience	Overall Complexity	Skill Level Required	Cost of Installation	Re-use and Disposal
Coir					
Woodfibre					
Pumice					
Perlite					
Rockwool					

Table 2. Summary of solution hydroponic system characteristics

Solution System	UK System Experience	Overall Complexity	Skill Level Required	Cost of Installation	Re-use and Disposal
NFT					
DWC / DFT					
Aeroponics					
Aquaponics					

Key

NFT: Nutrient Film Technique

DWC / DFT: Deep Water Culture / Deep Flow Technique

Suggested Trials for 2015

- The development of a robust substrate hydroponic production protocol for the culture of UK column stocks in coir and also solution hydroponics.
- This should include a comparison of stocks grown using coir in open containers, metal racks, gutters and also specific coir slabs.
- The suitability of existing crop support rack and growing gutter systems should be compared under UK growing conditions.
- Examination of practical solution hydroponic systems – such as Botman Hydroponics and 'Dry Hydroponics' – and their suitability for the production of UK cut flower crops, such as stocks and lisianthus.
- Comparison of other solid substrates for production of UK annual flower crops, including pumice, perlite and woodfibre products.
- The use of accurate dosing equipment and pH / EC monitoring should also form part of these trials.
- Production of reliable and specific nutrient target concentrations for input liquid feeds, rootzone and plant leaf tissue.
- Development of a strategy for recirculation of drain water from UK cut flower production systems, involving both solution hydroponics and substrate hydroponics.

Financial Benefits

Following investment in the appropriate hydroponic system and monitoring equipment, it is expected that a 10% minimum increase in yield of marketable cut flower stems will result.

In addition, improved control of pest and disease issues should be possible, further improving the overall marketability of the crop and reducing production costs.

It will also be possible to save the cost of energy and labour used for soil sterilisation.

Other savings will include water and fertiliser use and it is anticipated that a saving of up to 40% on water costs will be possible by precision irrigation and recirculation of nutrient solution or drain water.

Action Points

- Points to consider in choosing a suitable hydroponic system include, the degree of complexity required in the initial investment, the integration of the system with the existing crop production schedule and the cost of materials.

- Isolation of the hydroponic system or containerised substrate from the glasshouse soil will be essential to reduce the risk of disease contamination and spread.

- Initial considerations should include how to regulate, collect and manage drain water from the hydroponic system. If it is not possible to initially equip the installation for full nutrient recirculation, then future provision should be made for collection and storage of drain water.

- A thorough understanding of crop nutrition and the factors affecting nutrient availability in the hydroponic system needs to be acquired prior to installation.

- Once selected, the hydroponic system should be constructed and supplied with the appropriate accurate nutrient dosing control and monitoring equipment.

- The nutrient concentrations in background and stored water sources must be thoroughly checked by regular laboratory analysis and an appropriate nutrient recipe provided, to match the growth stage of the flower crop under cultivation.

- Nutrient targets are outlined in the science section of this report which will help steer plant growth and provide a nutritional base from which to refine the targets for specific flower types.

- Regular liquid feed, substrate, drainwater and leaf analysis must be employed to assist in crop growth decision management, to help achieve the optimum flower production and quality.

SCIENCE SECTION

Project Objectives

- To evaluate the development of hydroponic systems over the last 25 years, with particular reference to cut flower growing.
- To identify successful substrate types and hydroponic techniques, which may be suitable for current and future horticultural practices.
- To outline cultivation and nutritional difficulties encountered during earlier work on hydroponics.
- To recommend the most appropriate hydroponic systems for the cultivation of a range of flower crops.
- To determine the best forward route for pilot trials on the hydroponic systems identified in the review.

History of hydroponics

According to Benton-Jones (1982), "hydroponics is a widely and frequently used technique for growing plants without soil, providing for a considerable degree of the elemental environment surrounding the root. The technique has an interesting history of development and use dating back to the mid-18th Century, although the growing of plants in nutrient rich water may have dated back into the early history of man."

One advantage of horticultural production in hydroponic systems, as compared with growing in soil, is that external properties do not limit nutrient acquisition (Schwarz *et al*., 1997).

Peat

In commercial horticultural crop production, the move away from soil in the 1970s to peat-based systems was stimulated by the need to control problems with soil pests, diseases and nutritional imbalances.

In peat systems, practical problems with water content, water availability and nutrient balance limited its application to certain crops, such as tomatoes. All peat systems require a constant supply of nutrients, either in the form of a slow-release fertiliser or as liquid feeds. Depending on the composition of the background water, nutrient imbalances may quickly occur (Adams *et al.*, 1978), especially in the absence of regular nutrient sample analysis.

Moderate yields of tomato fruit may be grown in peat, provided that adequate levels of nutrients are maintained throughout the production season (Adams *et al*., 1973). Depending on the quantity of light received by the crop, a yield of up to 35 kg per square metre of classic round tomatoes may be achieved in a peat bag system over a nine-month production season. However, the yield of tomatoes was found to decline when the micronutrient status was not sustained, for example (Graves *et al*., 1978).

The overall professional use of peat grow-bags declined since the 1970s and most of the glasshouse food crops are now grown in alternative substrates (Bragg, 1990).

In 2011, a UK Government White Paper was published, in which the commitment to a reduction in the use of peat in UK horticulture was reaffirmed (Alexander and Bragg, 2014).

There are now other materials, as illustrated in Table 3, which may be used in place of peat for many sectors of commercial horticulture (Holmes and Lightfoot-Brown, 2000).

For peat alternatives to be viable competitive products in a commercial market, it is important to develop media with a guaranteed continuity of quality and supply (Dickinson and Carlile, 1995).

Both root aeration and water availability in the rhizosphere strongly depend on the physical properties of the substrates, which are influenced by the shape and size of their constituent particles (Savvas, 2007). The actual container capacity of a containerised substrate and thus the air-filled porosity and the water holding capacity depends on the container height.

Savvas (2007) stated that growing media dominated by fine particles tend to perform better when placed in pots or tall and narrow channels, while the cultivation in shallow bags or channels requires the use of coarser substrate grades.

Waldron *et al*. (2013) indicated that commercial peat and peat-based growing media retain a large level of plant cell wall structure, which provides the basis of their functional properties. It was added that industrially composted materials lack the same cell wall structure but that more controlled composting conditions could help to retain the properties. Three physical parameters (moisture retention, air-filled porosity and dry bulk density), in conjunction with nutrient analysis, provide a sound basis for evaluation of substrates and their structural suitability as growing media (Waldron *et al*., 2013).

Table 3. Alternatives to peat (Modified from Holmes and Lightfoot-Brown, 2000)

Peat alternative	Background	Main problems
Loam	Well-defined soil type, originally in 'John Innes' mixes. Traditionally lifted as turfs and stacked until stabilised.	Availability and variation between batches. High bulk density. High pH levels from some sources. High manganese after steam sterilisation.
Coir	Short to medium length fibres constituting the mesocarp of the coconut fruit. Excellent rooting, due to high air capacity. Low bulk density: 250-300 g per litre.	Non-indigenous product. Sample variation and supply reliability. High sodium and chloride concentrations. Nitrogen lock-up. Pre-treatment with calcium nitrate adds to the cost.
Coniferous barks **Scots pine / Corsican pine (main species)**	By-product of forestry industry. Bark is a sustainable material, as timber is a renewable resource. Disease-suppressive activity, due to the presence of fungi antagonistic to certain root pathogens. Bulk density of chipped bark low: 150-250 g per litre.	Bark must be matured, to allow phytotoxins, such as terpenes, to reduce. Low initial pH and low nutrient status. Barks immobilise nitrogen, during decay. Extra N fertiliser needed, especially for spruce barks. Low water-holding capacity, leading to increased leaching of nutrients.
Forestry residues	Waste from forestry operations. Low bulk density: 350 g per litre. Similar to bark but finer texture, with higher water-holding capacity.	Low initial pH. Higher water requirement than peat. Extra nitrogen needed.

Chipboard residues	Waste from chipboard sheet processing (milled and composted). Urea formaldehyde added, which releases N during the composting phase.	High pH. Higher water requirement than peat. High bulk density: 600 g per litre.
Green compost	European Landfill Directive and Landfill Initiative have diverted large volumes of organic wastes (brushwood / grass) away from landfill into composts. May contain beneficial microorganisms.	High pH and EC. High K and Cl concentrations. Contaminants, heavy metals and herbicides. High bulk density: 500-600 g per litre. High transport costs.
Other organic materials eg: composted sewage-based products, municipal solid waste, spent mushroom substrate, hop waste, coffee bean waste, cocoa bean shells, rice husks, bran, food industry wastes, paper wastes, digestate from anaerobic digestion process	Consumer resistance to sewage-based products. Possible concerns over use of digestate from anaerobic digestion process.	Availability of some products. High bulk density. Poor drainage / aeration. High pH and high nutrient concentrations. Contaminants, heavy metals and herbicides.
Inorganic materials **eg: rockwool, perlite, pumice, lignite, zeolite, polystyrene, urea formaldehyde resins.**	Some in use for many years. Low nutritional status allows precise nutritional control in hydroponics.	Rockwool: good in hydroponics but considered environmentally unfriendly, due to high transport costs and energy required for rockwool production. Disposal problems.

Nutrient film technique (NFT)

Nutrient Film Technique was developed in the early 1970s by Dr Allen Cooper and remains the ultimate nutrient recirculation system. According to Cooper (1975), the use of water containing dissolved nutrients, as a technique for crop production, was first described by Gericke in 1929.

The system consists of a water sump tank into which are dosed nutrients in various combinations (Graves, 1983). The quantity of liquid in the sump tank and the pH and electrical conductivity (EC) of the solution are both constantly monitored by a computer system and the appropriate changes made by the introduction of fresh water, acid and nutrients in liquid form, as required (Graves, 1986).

Traditionally, two dosing tanks were used to separate the phosphorus and calcium inputs until the point of introduction into the irrigation system (Drakes *et al*., 1984). This is to avoid precipitation of calcium phosphate and calcium sulphate, although this may occur inside irrigation tubing, drippers and in the substrate, after mixing and fertigation has taken place.

From the sump tank, the complete liquid nutrient feed is pumped to the top end of a series of closed troughs and the liquid feed then enters each trough through a delivery tube and moves evenly, by gravity, down a slope of 1 in 80 or 1 in 100.

The root system of each plant positioned in the trough is then bathed with water, containing liquid feed and dissolved oxygen. A root mat develops in the stream of water (Cooper, 1979) and the plants selectively remove nutrients and water from the solution, as the plant growth stage and environmental conditions dictate.

Cooper (1975) stated that as there is no drainage loss of water and little evaporative loss, the water requirement is reduced to the essential plant transpiration loss. Apart from being the first commercially acceptable recirculation system, NFT gave growers the best control of conditions in the root zone (Roe, 1982). In all other substrate systems, the roots are only partially visible and the substrate and feed have to be managed separately to give the best conditions for root growth in the substrate itself.

It should be noted that, in the NFT system rhizosphere, there is no buffering capacity – in that there is no actual substrate present – with the exception of the rockwool propagation material.

Since its early introduction, interest in NFT has waned for a number of reasons including: the high initial capital cost; system and equipment failures; nutritional problems; and plant losses through root disease (Burrage, 1993). System failures have included: faulty design; incorrect installation of equipment; and plant root death, due to oxygen starvation.

Nutritional problems have included: low nutrient solution pH, caused by acid overdosing; an accumulation of unwanted ions over time (for example, sodium, chloride and sulphate ions); and general nutrient solution imbalance problems.

Starting with high concentrations of unwanted ions in the background water only serves to compound nutritional difficulties later in the crop production process.

In addition, root death and subsequent disease problems have been caused as a direct result of stagnant conditions in the root zone and lack of skills, on the part of the grower, to understand basic plant health and nutritional requirements.

More recently, nutrient recirculation systems have been encouraged, due to their environmental benefits (Challinor, 2003). NFT is still successfully used for the production of long season tomato crops, in areas of the UK with good water supply characteristics, such as the Vale of Evesham.

Vermeulen *et al*. (2014) reviewed the likely reasons for the slow uptake of true hydroponic systems and the recent renewed interest in use of hydroponics involving water recirculation systems using only small quantities of substrate, or none at all.

It was concluded that the renewed interest has a number of regional drivers, such as depletion of land and societal interest in urban farming. However, to make hydroponic systems a lasting success, research effort should focus on reliable production: disease management, emission reduction and root development.

Aeroponics

Aeroponics is an air-water culture system, in which nutrients are supplied in a water mist directly to the bare root system of the plant (Nir, 1982). This technique has been used for both plant research and crop production (Christie and Nichols, 2004). Suitable crops have included tomatoes, cucumbers, potatoes, herbs, Lisianthus and Zantedeschia.

Rockwool (Stonewool)

The introduction of rockwool in the early 1970s revolutionised the crop production industry worldwide. The material is a by-product of the loft insulation industry and is produced by the heating and mixing-together of two rocks - basalt and diabase - at temperatures in excess of 1500°C, with the resulting flux then being spun into fibres and formed into slabs (Smith, 1987).

In its prepared state, rockwool has a pore volume of 97% and its function is to provide root anchorage for the plant and to regulate the water and air supply. It does not contain any plant nutrients and the plant must rely entirely on the inclusion of nutrients in the water supply (Bunt, 1988).

Rockwool does, however, initially require the reduction of pH from approximately 8.0 to 6.0 and a thorough wetting with nutrient solution, prior to use by the grower. If this initial wetting-up is not completed carefully and completely, it will lead to poor root colonisation of the rockwool, leading to subsequent irrigation difficulties and encouraging infection by opportunistic root diseases.

The rockwool slab is totally inert and does not participate in the process of movement of ions to the plant root, except that it provides air spaces and support for the root mat. If there is an imbalance in the ion content of the input feed, this will be mirrored in the root zone, as the rockwool fibres do not react with the nutrient solution.

There are concerns over pollution of the environment by waste nutrients and this has led to increasing interest in recirculation of the nutrient solution (Adams, 1993).

Total yields of up to 70 kg per square metre have been recorded in long-season UK classic round tomato crops grown hydroponically, using rockwool as a substrate.

Perlite

Perlite is a volcanic glass formed when molten lava cools very rapidly, trapping small quantities (2-5% w/w) of water. When crushed and heated to 1,000°C, it expands to form white, lightweight aggregates with a closed cellular structure.

These aggregates are virtually inert, stable, have a low bulk density and do not break down when mixed with other materials (Day, 1991). Water is retained only on the surface of the aggregates and compost mixes containing perlite, for example, are well drained.

A perlite tomato culture system was developed at the West of Scotland Agricultural College and utilised 30 litre bags of perlite, with a shallow reservoir of nutrient solution (Szmidt *et al*., 1988).

Plants grown in perlite are totally dependent on liquid feeding (Bunt, 1988). Perlite has a negligible cation exchange capacity and has a nominal pH of 7.0 to 7.5. It is resistant to steam temperatures, so it may be sterilised as required (Smith, 1996). As with rockwool systems, the excess irrigation solution is allowed to run to waste, or the drainwater may be captured and recirculated back to the growing crop (Olympios, 1993).

Pumice

Pumice is a highly vesicular volcanic glass, silicic in composition and occurs as massive blocks or unconsolidated, fragmented material (Mitchell and Bloodworth, 1989). Volcanic magma contains 2-3% water and, on entering the atmosphere during an eruption, this water evaporates rapidly causing expansion of the material (Gunnlaugsson and Adalsteinsson, 1995). This may solidify on contact with the atmosphere as a vent filling or flow, or may be shattered by a violent eruption (Robbins, 1984).

One example of pumice is Hekla-pumice, which originated from the Hekla volcano in Iceland over 2,800 years ago. It should be noted that pumice is inexpensive, biologically inert and contains no pathogens or weed seeds (Gunnlaugsson and Adalsteinsson, 1995).

Pumice is a stable material, which can withstand steam sterilisation without a major loss of structure (Smith, 1996). All intensive cropping systems involving pumice require liquid feeding to sustain the growth of plants.

The Mediterranean island of Lipari, which lies 35 km off the northern coast of Sicily, is the focus of the Italian pumice industry (McMichael, 1990). Sicilian pumice has a pH range of 7.0 to 8.0 and a conductivity of 200 μS per cm at 20°C. Its air-filled porosity range is 20 to 35% and extractable sodium 30 to 35 mg per litre (Challinor, 1993).

There was much interest in the use of pumice in Holland during the 1990s and many trials using Sicilian pumice were also completed on long-season flower crops at the Department of Agriculture, Fisheries and Food, Howard Davis Farm, Jersey during the period 1989 to 1998.

Current uses of pumice in floriculture include long-season production of roses in Kenya, using local supplies of the volcanic material (Figure 6).

Figure 6. Kenyan roses growing in pumice

Zeolites

Zeolites are crystalline, hydrated, framework aluminosilicates of alkali and alkaline earth cations that are characterised by three-dimensional structures containing channels in which are located cations and water molecules (Mumpton, 1984; Dyer, 1988; Ming and Mumpton, 1989).

Water may be lost and re-gained and cation exchange can occur between the zeolite substrate and plant roots. Clinoptilolite is a form of zeolite, which has a particular affinity for monovalent ions, such ammonium-nitrogen and potassium (Tsitsishvili *et al*., 1992).

Care is required in selection of the zeolite material, as some may contain high concentrations of sodium (Weber *et al*., 1984). The release of the cation in the rhizosphere and subsequent uptake by plants may result in salt stress symptoms and crop damage (Pirela *et al*., 1984; Ferguson *et al*., 1986; Nus and Brauen, 1991; Yi *et al*., 1991). Therefore, sources of zeolite low in sodium and high in potassium and calcium are essential for applications in intensive glasshouse systems (Challinor, 2003).

Hershey et al. (1980) used leaching experiments to compare the release of potassium ions from untreated clinoptilolite with the release from soluble potassium nitrate, when each was added to a sand-peat-sawdust potting mix. Clinoptilolite was naturally high in exchangeable potassium (160 meq per 100 g). Potassium release curves indicated that clinoptilolite behaved similarly to a slow-release fertiliser.

Hershey et al. (1980) also completed a glasshouse experiment in which all the potassium required by a three-month crop of pot chrysanthemums was supplied by clinoptilolite in the place of liquid potassium feeds. They found that 50g of clinoptilolite per 1.5 litre potting media (30% sand, 35% peat and 35% composted sawdust) produced yields equal to those obtained from daily irrigation of un-amended potting soil with 234 mg per litre potassium.

Coir (Cocopeat)

Coir is a waste ligno-cellulose material produced during the preparation of coconuts for food use (Verdonck *et al*., 1983). The outer husks of coconuts are rendered down in water to extract long fibres, which are used in coconut matting. It is the spherical particles that comprise coir dust (Figure 7).

One advantage of using cocofibre is that it has a relatively uniform particle size range and this is useful in avoiding waterlogging, when used as a substrate.

However, coir has little buffering capacity and can be easily leached of soluble nutrients (Bragg, 1995).

The initial pH is usually lower than most compost-based substrates and may range from 5.4 to 6.8, for example. Coir also has a low bulk density of 250-300 g per litre.

Although the coir product may have been irrigated with water, prior to shipping, it is important to check the initial coir batch sodium and chloride concentrations. Depending on the treatment of the coir prior to wetting-up, it may be necessary to reduce high concentrations of sodium and chloride by flushing with water, before planting the crop.

Figure 7. Coir pith and fibres

Woodfibre

Woodfibre is shredded timber, which may have been treated with alkali to dissolve sugars involved with the microbial breakdown of the wood (Bragg, 1995). As a result, the initial pH level may be higher than 6.5.

There is little buffering capacity and a good starting air-filled porosity (AFP). However, the AFP reduces as the fibres become fully wetted and the woodfibre tends to partially slump over the growing season.

Bark, which has been composted for two to six months, is characterised by high air contents and good drainage properties. Bark from *Pinus sylvestris* and *Pinus nigra* var. *maritima* is widely used in the European production of large container-grown plants (Carlile, 2008).

Intensification of commercial hydroponic systems

Most of the systems referred to above are now used in large-scale glasshouse cultivation of salad crops and an average nursery unit size of 10 hectares is not uncommon across the main glasshouse crop production areas in the world (Figures 8, 9 and 10).

Figure 8. Fertigation equipment for a 10 hectare tomato nursery (Holland, 2014)

Figure 9. Nutrient stock tanks for a 10 hectare tomato nursery (Holland, 2014)

Figure 10. Slow sand filtration tanks on a tomato nursery using drainwater recirculation (UK, 2014)

Achieved total yields and overall quality of crops produced in intensive hydroponic systems have both improved dramatically over the last 40 years. This reflects: improvements made in plant varieties and crop growing structures; developments in environmental control systems; understanding of plant nutritional requirements; and also augmentation of the skill levels of the grower-producers.

Hydroponic systems allow plant growth characteristics to be very carefully controlled. For example, the establishment of the plant, following contact with the substrate, is essential to develop an extensive root system. This will allow the effective absorption of water and nutrients for the remainder of the production period. The encouragement of vegetative growth, in order to produce leaf growth for crop development, or for harvest, is more easily managed in hydroponic systems. The switch from vegetative to generative growth, in order to stimulate the production of flowers and fruit, is also more easily managed in intensive growing systems, when compared to field-scale operations.

Most of the major long-season salad crop plants -- such as tomatoes, cucumbers and peppers -- are now grown in hydroponic systems under glasshouses in the UK. Herb plants for final sale as growing plants in supermarkets are now grown in pots on benches, using hydroponic irrigation systems to provide water and nutrients.

Soft fruit crops, such as strawberries and raspberries, may also be grown in bags or modules under glass or in plastic tunnels, using hydroponic irrigation systems.

Organic vegetables and fruit are required to be grown in soil under UK Soil Association rules, for example. Using organic tomatoes as a specific example, achieved total yields are lower than in hydroponics and the risk of exposure of the plants to soil-borne pest, disease and virus problems is greatly increased in unsterilised soil.

Investment in these more intensive crop production systems is expensive but the yield and quality of the plants is potentially optimised, as a result.

Vermeulen *et al*. (2014) commented that, over the last five to ten years, there has been renewed international interest in hydroponic systems requiring little or no substrate, such as NFT and deep flow technique. As mentioned earlier, NFT for example, has been in existence for over 40 years. There would appear to have been a lack of support for and exchange of knowledge in the further development of solution hydroponics.

Vermeulen *et al*. (2014) concluded that the renewed interest has a number of regional drivers, such as depletion of land and societal interest in urban farming. To make hydroponic systems a lasting success and to ensure reliable production, it was suggested that research effort should focus on root development, disease management and reduction of emissions.

Growers will also need support to learn how to operate these systems effectively and also to improve knowledge on plant nutrition.

Hydroponic hobby kits

The hobby grower or amateur gardener faces a similar set of problems with the use of hydroponic kits, as outlined above for the commercial grower. For example, the same problems exist with the need for precise control of the pH and nutrient concentration of the feed solution. On further intensification of these systems, the following problems will also need to be addressed:

continuous control of the environment, involving the provision of light for plant growth and regulation of air temperature and humidity levels;

the use of energy-saving devices, such as thermal screens and electrical timers;

collection and treatment of drainage water, following irrigation to the plants; and

supply and control of supplementary carbon dioxide, to encourage consistent plant photosynthesis and uniform growth.

In addition, the following equipment and materials are also required for these intensive systems:

heating source and thermostatic control, to regulate temperature and humidity;

fan ventilation, to remove stale air and replenish carbon dioxide concentrations;

electrical pumps to supply and recirculate irrigation water;

compost or substrate;

water supply; and

solid and liquid fertilisers.

Such precise manipulation of the environment and irrigation pattern for the crops demands a good knowledge of plant growth and the chemistry involved in plant nutritional requirements. To ensure success, the grower requires a thorough understanding of the subject, experience in managing such systems and practical ability.

Monitoring of the irrigation system requires the following equipment:

pH and conductivity meter; and

multi-ion hand-held probe or laboratory analysis of solution sample.

Measurement and precise control of pH is essential, to ensure that the plant roots are able to absorb nutrients continuously. If the pH is too acid (pH lower than 5.5, for example) or too alkaline (pH higher than 7.0, for example), then nutrient availability will be suppressed. It is important to balance the supply of nutrients to the plant, in order to avoid nutrient deficiency symptoms or poor quality flowers and fruit.

Multi-ion probe technology has improved over the last 10 years and it is now possible to purchase a hand-held probe, which will measure potassium, calcium, sodium, chloride, nitrate-nitrogen and ammonium-nitrogen.

However, regular sampling and laboratory analysis of liquid feed solutions is essential to provide a clear picture of plant nutrient availability of a total of 15 major and minor elements and the balance between nutrients, such as potassium, calcium, magnesium and nitrate-nitrogen.

Summary of Three Cut Flower Substrate Experiments Completed on Jersey, Channel Islands (1989 to 1998)

Introduction

This section of the report summarises experimental work completed on flower crops grown in substrates at the Department of Agriculture, Fisheries and Food, Howard Davis Farm, Jersey from 1989 to 1998.

The primary reason for the experimental work was to investigate how the main Jersey flower crops could be grown hydroponically, whilst maintaining or improving flower quality characteristics and reducing the incidence of plant disease.

In the case of standard and spray carnations, for example, losses of plants from *Fusarium culmorum* (stub rot) and *Fusarium oxysporum* (wilt) were becoming unacceptably high in soil-grown crops. The use of sheet steaming formed part of the crop rotation protocol but results were often variable, due to poor soil preparation, insufficient steam contact time with the soil or variable soil temperature control.

Re-infection of the soil with disease organisms carried on new plant cuttings was also common.

The first experiment included in this report compared a peat substrate system with two peat alternatives, namely cocofibre and woodchips. The results illustrated the physical and chemical changes recorded in the substrates over two years. This constitutes a useful guide to how similar peat alternatives are likely to perform with intensively grown flower crops, such as antirrhinums (*Antirrhinum majus*), lisianthus (*Lisianthus russellianum / Eustoma russellianum)* and stocks (*Matthiola incana*).

In terms of the physical substrate measurements, the experiment recorded dramatic changes in the air-filled porosity of the peat alternatives over 22 months.

In addition, the experiment also included the aluminosilicate substrates pumice and clinoptilolite zeolite. Both clinoptilolite and nutrient-loaded clinoptilolite were tested, to determine if there were benefits to the growing crop from the physical and chemical attributes of the zeolites.

Clinoptilolite is able to adsorb cations, such as ammonium-nitrogen, potassium and calcium and has a high cation exchange capacity. These characteristics are useful when considering how to use liquid fertilisers more effectively and prevent contamination of external water systems by crop drainwater.

A comparison of standard carnation (Dianthus caryophyllus) flower yield and quality from plants grown on six substrates: peat, cocofibre, woodchips, pumice, unloaded clinoptilolite and nutrient-loaded clinoptilolite (1992 to 1993).

Objectives

1. To compare a range of substrates in the production of standard carnations grown in hydroponics under modern, computer-controlled, glasshouse environmental conditions.
2. To compare the flower production and quality of a range of varieties over a 19-month harvest period.
3. To measure the changes in the drainwater nutrient concentrations of the substrate systems, with particular emphasis on drainwater nitrogen concentration.

Materials and Methods

Peat / Peat Alternative Substrates

The dry Vapo peat boards were supplied in plastic sleeves measuring one metre by 15 cm in width. On wetting-up, the slabs had a total volume of 45 litres and 16 plant cuttings were then inserted into each hydrated peat board (2.81 litres per plant).

The Golden Grow / Dutch Plantin cocofibre was supplied loose and, after pH adjustment, was transferred to five litre, black polypropylene pots. The pH of the cocofibre was modified by the addition of ground limestone at a rate of 2.6 kg per cubic metre, in order to increase the initial rootzone pH from 5.0 to 6.2. Cuttings were inserted at four per pot (1.25 litres of coir per plant).

The woodchip substrate was utilised, as supplied. Each woodchip bag measured one metre by 15 cm and incorporated an inner liner of clear plastic netting enclosing the woodchips, contained within an outer plastic sleeve. Eight cuttings were inserted into each substrate module (2.00 litres per plant).

Drainage slits were made in each sleeve, to allow drainwater movement out of the plastic modules.

The cuttings of ‘Yellow Candy’ (Selecta), ‘Master’ (Barbaret and Blanc) and ‘Sahara’ (Shemi) were planted over the period 19-21 February, 1992 and the final flower harvest was on 31 December, 1993.

Plant density was arranged as 32 plants per square metre and the varieties were replicated three times on each substrate, in a fully randomised trial design.

Results

As the overall crop irrigation requirements were based on the moisture content of the cocofibre pots, it was more difficult to accurately monitor and manage the moisture content of the two substrates contained in modules. As a result, there were problems with overwatering during the winter and, in particular, the woodchip bags became waterlogged and a rapid decomposition of the contents ensued. As a result, each woodchip bag slumped over the growing season, causing a reduction in air-filled porosity.

The peat boards were also susceptible to overwatering, particularly during the winter months. As a result, disease problems – such as *Fusarium culmorum* (stub rot) – contributed to poor crop growth following the winter period (MAFF, 1967) and caused subsequent plant losses.

Air-filled porosity

A series of three air-filled porosity measurements were taken before and after use for each substrate and these revealed that the AFP values of the woodchips and cocofibre reduced by more than 50% over the 22 month growing period (Table 4).

Table 4. Air-filled porosity measurements for three substrates

Substrate	Mean original AFP%	Mean final AFP%	% reduction
Peat	16.4	13.8	15.9
Cocofibre	25.4	11.1	56.3
Woodchips	63.8	30.3	52.5

The first flower harvest from the peat and peat alternative substrates was on 15 June. There were no significant differences between Class I flower yields per square metre of the varieties 'Yellow Candy', 'Master' and 'Sahara' grown on peat, cocofibre and woodchips.

The highest total marketable production of 'Yellow Candy' flowers was recorded from the woodchip plots at 503 stems per square metre and, in comparison, the highest marketable flower totals from the peat and cocofibre plots were 459 and 432 blooms per square metre, respectively.

Aluminosilicate Substrates

All substrates were placed in five litre, black polypropylene pots and plant cuttings were inserted at four per pot. The volume of pumice, unloaded clinoptilolite and nutrient-loaded clinoptilolite was 1.25 litres per plant. Eight pots per metre length of bed were positioned in a double row layout, to give a plant density of 32 plants per square metre.

The cuttings of 'Yellow Candy' (Selecta), 'Forever' (Lek and Zonen) and 'Omagio' (Shemi) were planted over the period 19-21 February, 1992 and the final flower harvest was on 31 December, 1993.

Results

The crop irrigation requirements were based on the moisture content of the clinoptilolite substrates. Particle size distribution in the clinoptilolite substrates was very even, resulting in rapid surface drying. Evaluation of moisture at the pot surface, particularly at the start of the trial before full crop cover had been reached, was a particular problem related to the zeolite substrates.

The first flowers were harvested on 10 June and there were no significant differences between Class I flower yields per square metre of the varieties 'Yellow Candy', 'Forever' and 'Omagio' grown on pumice, unloaded clinoptilolite zeolite and nutrient-loaded clinoptilolite zeolite 'Hydrocult S'. The highest total production of 'Yellow Candy' flowers was recorded from the pumice plots, with 447 stems per square metre.

Statistical analysis of the combined Class I flower yields per square metre for the variety 'Yellow Candy' on all six substrates (peat, peat alternatives and aluminosilicate materials) indicated that there were no significant differences between the substrates.

Summary of Nutrient Concentration Changes

Peat / Peat Alternative Substrates

Both peat and cocofibre exhibited a steady drainwater nutrient profile over the first year. However, the woodchip substrate appeared to leach more nutrients through both years, for example ammonium-nitrogen, nitrate-nitrogen and potassium.

Cocofibre appeared less stable during the second year, with more variation in the concentrations of nutrients in drainwater samples.

The woodchip substrate leached more sodium and this coincided with higher EC concentrations in September, 1993. This was due to temporary drying-out of the woodchip substrate.

It was apparent that more potassium, calcium and phosphorus were removed from solution by plants during the major flower flushes.

Manganese drainwater concentrations were consistently low throughout from the cocofibre substrate. There was also evidence of a lower iron concentration in the cocofibre drainwater samples through the experiment.

Aluminosilicate Substrates

The clinoptilolite substrates adsorbed potassium (Hershey et al., 1980), especially in the first year and released calcium into the drainwater over the same period. The nutrient-loaded clinoptilolite appeared to adsorb more potassium and release more calcium than the unloaded clinoptilolite. In addition, the nutrient-loaded clinoptilolite also appeared to release more nitrate-nitrogen, magnesium and phosphorus into drainwater during the first six months.

Initially, there was a higher concentration of ammonium-nitrogen in drainwater from the nutrient-loaded clinoptilolite.

Both clinoptilolite substrates released more sodium at the start of the experiment compared with pumice. The higher release of nutrients, for example calcium, magnesium and sodium, coincided with higher EC readings over the first six months from the nutrient-loaded clinoptilolite.

According to Semmens (1984), ion size, valence and hydration energies are important factors in determining selectivity of a given ion in a specific system. For example, large cations, such as K^+, Pb^{2+}, Ba^{2+} and NH_4^+ are extremely well removed by clinoptilolite but smaller ions, such as Li^+, Na^+ and Ca^{2+}, are very poorly removed. The contact time available for exchange to occur also influences the cation exchange performance of natural zeolites. This helps to explain the apparent preference shown by clinoptilolite for adsorption of potassium and ammonium-nitrogen in relation to calcium, magnesium and sodium recorded during the experiment.

Conclusions

- It was possible to grow standard carnation plants and produce commercially acceptable yields of quality flowers over a two-year period on all substrates during the experiment.
- The provision of liquid feeds resulted in an even supply of available nutrients to plants growing on all substrates during the crop establishment period.
- The nutrient-loaded clinoptilolite produced a good yield of standard carnations and the additional availability of nutrients during the first six months could have helped to improve growth and flower quality.
- Unloaded clinoptilolite performed as well as pumice in five litre pots, over a 22-month growing period.
- The moisture content of the aluminosilicates was critical to the early rooting and establishment of the carnation cuttings. However, the excellent air-filled porosity and drainage characteristics of the aluminosilicates ensured a better winter performance and plant survival rate, in comparison with the peat, cocofibre and woodchip substrates.
- Of the peat and peat alternative substrates, the variation in concentration and release of nutrients from the woodchips into the drainwater was most marked, especially in the second year of production.
- As part of the cation exchange processes involved, the nutrient-loaded clinoptilolite also released quantities of nutrients into the drainwater, particularly at the start of the experiment.

Summary information from two additional experiments involving nutrient loaded clinoptilolite is also included in Appendix I and Appendix II.

The first experiment involved standard carnations growing in nutrient-loaded clinoptilolite with a water-only irrigation strategy (Appendix I). Commercially acceptable yields of high quality standard carnations were produced in this experiment with a nutrient-loaded clinoptilolite, ‘Hydrocult S’, using only water in the irrigation cycles.
The main nutritional limiting factor to plant growth was nitrogen and the substrate was depleted in ammonium-nitrogen by the end of the first flower flush.
Subsequent production of shoots was limited by the availability of nitrogen from the substrate and from the irrigation water.

As phosphorus is not held as a cation within the clinoptilolite matrix, an initial release of phosphorus, as phosphate, was expected in the first drainage flushes.
However, the plant leaf sap analysis results indicated that there was an adequate concentration of phosphorus in the new leaf tissue and that there were no phosphorus deficiency symptoms evident in the crop canopy.
The zeolite released potassium ions, which were readily absorbed by the plants and it is likely that an interaction with calcium and magnesium was involved in the cation exchange process.
Sap analysis results indicated that there was a lower concentration of calcium present and this was probably more related to plant uptake from the root zone and subsequent internal plant transport under the influence of glasshouse humidity levels.
Any cations released into the root zone later in the experiment were probably absorbed quickly by active plant roots or re-adsorbed by the clinoptilolite.
It was noticeable that there was a low level of root and stem base disease problems over the winter period in this crop. This could have been due to a combination of dry substrate surface conditions and the lower availability of nitrogen thus preventing excessive vegetative growth.

In the second experiment, nutrient-loaded clinoptilolite irrigated only with water was directly compared to pumice and foam being irrigated with liquid feeds (Appendix II).
The main conclusions were summarised as follows. The nutrient-loaded clinoptilolite substrate loadings of ammonium-nitrogen and phosphorus were the main nutritional limiting factors affecting plant growth and flower yield.
Drainwater nutrient concentrations were low throughout the experiment from the nutrient-loaded clinoptilolite plots, whilst drainwater from the fertigated pumice plots contained notably higher concentrations of nitrate-nitrogen, phosphorus and potassium.
Leaf tissue analysis revealed lower total nitrogen and total phosphorus concentrations in leaves sampled from plants growing in nutrient-loaded clinoptilolite.
The clinoptilolite cation exchange mechanism involved potassium, calcium, magnesium and sodium as the major participating ions. The clinoptilolite total potassium concentration decreased and the total calcium, magnesium and sodium concentrations increased over the experimental period. The clinoptilolite total phosphorus concentration decreased during the experiment and the release of phosphorus ions could have been related to and regulated by the accumulation of calcium in the substrate.
It is clear that loading of ammonium-nitrogen in nutrient-loaded clinoptilolite was sufficient to produce commercially acceptable yields of standard carnations over an eight-month period.
Therefore, in order to compete with flower production from a fertigated pumice crop, it would

be necessary to supplement the nitrogen and, possibly, the phosphorus contents of the nutrient-loaded zeolite by the introduction of a liquid feed of ammonium nitrate or mono-ammonium phosphate, for example.

Careful nutritional monitoring of the system would be required, however, as the introduction of NH_4^+ into the root zone would tend to decrease the pH by release of H^+ ions and also encourage cation exchange with the clinoptilolite, with the possible release of high concentrations of accumulated sodium ions.

These experiments have provided useful information on the performance of flowering plants in both peat alternatives and aluminosilicate substrates over long cropping cycles.

This has enabled the formulation of reliable liquid fertiliser recipes for hydroponic flower production and also for the creation of optimum nutrient concentration targets for specific flower crops.

Optimum nutrient concentrations

Following the section on experimental substrates, an example of a range of target specifications is summarised in tables 5-9, to provide an indication of suitable hydroponic flower nutrient concentrations and nutrient balances.

The far left hand table column lists the most important elements to be measured in the analytical laboratory and also the ratio between the major nutrients.

EC is the electrical conductivity of the solution, which reflects the total concentration of ions in solution.

The elements are further divided into major and trace, plus a reference to unwanted ions, for example sodium, chloride and sulphate. Although useful to control plant growth under low light or winter conditions, high concentrations of sodium and chloride will decrease the availability of water for plant uptake and may result in nutrient imbalances or in crop yield reduction.

The three colour-coded columns indicate the nutrient concentration ranges for production of flower crops in hydroponic systems: red (problem), amber (warning) or green (acceptable).

Using potassium (K) as an example, the optimum concentration required for healthy plant growth and good quality flower production in a commercial hydroponic system is 250 mg per litre. A concentration below 200 mg per litre in the substrate root-zone would limit potassium availability for the plant and is likely to result in flower quality issues, such as poor colour intensity and a reduction in vase life. A concentration above 500 mg per litre would constitute an excessive value but is unlikely to cause plant toxicity problems. However, such a high concentration may cause a reduced availability of other elements, such as calcium or magnesium.

With a potentially unwanted element, such as sodium (Na), the root-zone optimum concentration is 200 mg per litre. A concentration above 400 mg per litre is likely to increase the plant uptake of sodium, which will substitute for potassium, calcium and magnesium. If this trend continues, plant growth, yield and flower quality issues are likely to result.

In the case of a trace element, such as zinc (Zn), the optimum concentration required for normal plant growth is 0.5 mg per litre. A concentration below 0.3 mg per litre is likely to increase the risk of zinc deficiency symptoms occurring. The development of any plant nutrient deficiency will tend to reduce yield and flower quality. As there is a complex link between phosphorus, manganese and zinc availability to plants, it is very important to ensure that the nutrient balance is as precise as possible (Table 9).

The document is included as an example of the importance of nutrient balances in commercial hydroponic systems and the complexity of maintaining the nutritional balance in such a system, to provide optimum crop quality and yield.

As indicated earlier, without the necessary understanding of such chemical relationships and plant interactions, the risk of system / crop failure is much increased.

Table 5. Hydroponic cut flower rootzone pH and EC targets (adapted for flowers from Challinor, 2014)

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 6. Hydroponic cut flower rootzone main element target concentrations (adapted for flowers from Challinor, 2014)

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 7. Hydroponic cut flower rootzone unwanted ion target concentrations (adapted for flowers from Challinor, 2014)

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 8. Hydroponic cut flower rootzone trace element target concentrations (adapted for flowers from Challinor, 2014)

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 9. Hydroponic cut flower rootzone main element nutrient ratios (adapted for flowers from Challinor, 2014)

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

By way of illustration of the physical and chemical properties of coir and also its suitability as a plant growth substrate, the following section describes a 2013 observation trial involving tomato plant growth in coir, coir mixed with digestate and bark mixed with digestate.

The information is of particular relevance to the cut flower grower, as it highlights the recommended analytical measurements, which will be required on managing cut flower hydroponic systems and also summarises changes in coir pH, EC, bulk density and nutrient concentrations over eight months.

Actual Example of Coir Substrate Analysis (after Challinor, 2014)

The use of cattle slurry digestate solids in mixtures with coir and pine bark as plant growth substrates in the intensive production of glasshouse tomato crops

Summary

Following the process of anaerobic digestion, cattle slurry digestate solids were combined with coir and also pine bark. The substrates were then compared with a standard commercial coir slab to produce a late-planted, classic round, glasshouse tomato crop.

Samples of applied liquid feed, crop drainwater and tomato plant leaf tissue were taken at regular intervals and comparisons made between the standard growing medium and the substrate mixtures. Substrate samples were also taken as fresh and used samples, in January and October, respectively.

Plants were affected by the high pH conditions in the substrates containing digestate and changes to the feed regime were used to improve the rootzone pH and also the iron and manganese availability for plant uptake.

Although the digestate mixtures contained comparatively high concentrations of the heavy metals chromium and nickel, plant growth did not appear to be adversely affected during the trial.

It was possible to steer tomato plant growth in both the digestate mixtures over a period of eight months and obtain similar plant yields and fruit quality to the standard coir substrate.

Table 10. Physical and chemical properties of coir (fresh samples)

Parameter	Unused Coir (February, 2013)	Unused Coir and Digestate	Unused Bark and Digestate	Used Coir (October, 2013)	Used Coir and Digestate	Used Bark and Digestate
pH	6.4	8.8	8.5	5.65	6.98	6.9
Conductivity µS/cm 20°C	267	413	381	1,130	1,150	926
Bulk Density g/l	412	423	468	354	446	535
Dry Matter % m/m	12.9	22	27.1	14.8	20.4	23.8
Moisture % m/m	87.1	78	72.9	85.2	79.6	76.2

Table 11. Water extractable nutrients: major elements (fresh samples)

Parameter	Unused Coir (February, 2013)	Unused Coir and Digestate	Unused Bark and Digestate	Used Coir (October, 2013)	Used Coir and Digestate	Used Bark and Digestate
Ammonium-N mg/litre	< 1	< 1	< 1	2.54	< 1	< 1
Nitrate-N mg/litre	< 5	28.7	11.3	300	176	268
Phosphorus mg/litre	8.08	63.8	64.2	121	38.6	49.1
Potassium mg/litre	282	488	447	545	520	524
Calcium mg/litre	1.45	19.6	26.6	388	329	244
Magnesium mg/litre	< 1	12.6	18.7	220	280	183
Sodium mg/litre	80.6	106	85.5	98.3	126	85.9
Chloride mg/litre	334	195	141	538	591	402
Sulphur mg/litre	3.15	30.7	41.1	207	261	158

Table 12. Water extractable nutrients: trace elements (fresh samples)

Parameter	Unused Coir (February, 2013)	Unused Coir and Digestate	Unused Bark and Digestate	Used Coir (October, 2013)	Used Coir and Digestate	Used Bark and Digestate
Iron mg/litre	< 0.5	0.875	0.569	0.988	< 0.5	< 0.5
Manganese mg/litre	< 0.1	< 0.1	< 0.1	0.14	< 0.1	< 0.1
Boron mg/litre	0.184	0.231	0.229	2.66	2.56	1.32
Zinc mg/litre	< 0.1	< 0.1	< 0.1	0.733	1.34	0.87
Copper mg/litre	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Molybdenum mg/litre	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

The pH results for unused coir mixed with digestate and unused bark and digestate were 8.8 and 8.5, respectively. In comparison, the unused coir pH was much lower at 6.4.

On completion of the trial, pH measurements were lower, with both digestate mixtures at approximately 6.9, compared with coir at 5.65.

EC concentrations of the unused digestate substrate samples were higher than coir but measurements taken on the substrates at the completion of the trial were all higher than in the unused samples.

The water extractable nitrate-nitrogen concentration in the unused bark and digestate sample was lower than in the unused coir and digestate sample suggesting that there may be partial retention of nitrate-nitrogen by the bark fraction of the mixture.

Current Flower Hydroponic Systems

Kenya

Grower Visit to Finlay Flowers, Kericho: 15 October, 2013

Although there are soil-grown rose crops on this site, 82% of the production is in a contained pumice system. The key drivers for the move to hydroponics are the cost of fertilisers and water, coupled with the attendant risk of pollution from drainwater nutrient solutions.

The main advantages of using a hydroponic production system were reported as: a 10% increase in flower production; savings in fertiliser and water use; and easier management of pest and disease problems.

The pumice system drainage percentage was quoted as 32 to 36% and the drainwater nutrient solution is captured and recirculated back to the growing crop. The initial density used is 10 plants m^{-2}.

Local volcanic pumice has a pH of 8 to 10 and is first flushed with water to reduce its innate sodium concentration. Phosphoric acid is then used to acidify liquid feeds and to reduce the rootzone pH to 5.8 to 6.2.

There were two drip irrigation lines per pumice bed, with an irrigation capacity of 4 litres m^{-2}. Each pumice bed has a depth of 12.5 to 15cm and is constructed with more coarse pumice at the base of the trough (Figure 11).

Following planting, the establishment period lasts for 8 to 12 weeks and the plants are then subjected to an initial bending of existing shoots. The aim of this is to stimulate the formation of 4 to 6 strong flowering stems per plant.

Sweetheart types take 45 days to flower in each cycle, intermediate types 56 days and T-hybrids 65 days.

Crops are in production for 6 years and the trial house tests varieties over a two-year period.

Figure 11. Use of pumice for rose production

Pest and Disease Problems

Pest control is achieved using a 100% integrated pest management approach. Introductions of *Phytoseiulus persimilis* are used against spider mites, for example.

Disease control is more of a challenge, as humidity levels vary through the day and botrytis and powdery mildew can be troublesome. *Bacillus subtilis* has been tested against established botrytis infections but is considered to be more effective when used as a preventative treatment.

Laboratory Analysis

Pumice system nutrient solution testing and rose crop leaf analysis takes place on a quarterly basis. Regular pH and EC testing is completed at the farm.

Holland

Grower Visit to Kreling Chrysant B.V., Bruchem: 24 April, 2014

Kreling Chrysant is a family business and is considered to be the largest chrysanthemum grower in the world. It is also co-owner of Chrysanthemums Kreling Deliflor Hoogveld B.V., providing 225 million rooted cuttings annually. Kreling Chrysant cultivates approximately 100 million stems each year including a wide range of varieties (Figures 12 and 13).

Figure 12. Kreling Chrysant soil-grown plants

Figure 13. Kreling Chrysant flowering plants in soil

In The Netherlands, there are 700 hectares of cut flowers grown in soil (Eveleens and Blok, 2014). There are concerns regarding the control of soil pathogens and also the risk of watercourse pollution, from drainwater containing mineral fertilisers.

Therefore, work is in progress to find a suitable hydroponic recirculation system for the year-round (AYR) production of cut flower chrysanthemums, without drainwater moving through the soil profile and contaminating water systems.

In 1995, Wilson and Finlay stated that there was renewed interest in developing hydroponic systems for UK AYR chrysanthemums, arising from both environmental concerns over the emission of chemicals into the sub-soil and the potential for improvements in flower quality (particularly for the winter-grown crop). Successful production of AYR chrysanthemums was achieved on recirculating sand-based systems and these crops outperformed those grown in soil with taller and heavier stems (Wilson and Finlay, 1995).

A deep flow waterbed and an aeroponic system were also found to produce consistently good quality stems (1 g fresh weight per cm stem) in Dutch work. Aeration of the deep flow waterbed system gave 10% more fresh weight per stem (Eveleens and Blok, 2014).

Chrysanthemum (*Dendranthema grandiflora*) trials have included direct-rooting plant cuttings in rigid aluminium cassettes or plastic channels, without any growing medium (Figure 14). This eliminates the cost of the transplant compost and related labour (Hansen, 1999). The small, cost-effective channels had an internal cross section of 3.2 x 3.2 cm. This allows for high initial plant densities when the channels are placed together and accounts for a good utilisation of glasshouse floor space.

The channels may be fitted with removable plant support mechanisms, so that additional crop supports will not be required for the first 6 to 8 weeks. Cleaning and re-use should be simple, following harvest.

The channels could be positioned on transportable benches, without a fixed-line nutrient solution supply, thus allowing movement of the crop, so that all labour inputs can be focussed on a central, customised location.

Figure 14. Rooting of chrysanthemum cuttings in solution hydroponics

This idea is similar to production of roses on rockwool, where the growing crop is moved automatically on suspended gutters or benches to a central point for harvesting and additional pruning, for example.

At Kreling Chrysant, the water quality is considered to be very important for hydroponics. Due to concerns over the concentration of sodium and chloride ions in background water supplies and also accumulating in the recirculation system, it may be necessary for Kreling Chrysant to invest in reverse osmosis equipment going forward.

A 10cm depth of water is used in the system and hydrogen peroxide (35%) is used to reduce bacterial growth in the system and also to provide oxygen in the water (Figure 15). Air was originally bubbled into the solution-mixing tank but this did not provide a sufficiently consistent concentration of oxygen.

The formation of roots in the solution takes 17 to 19 days, after insertion of the cutting into the channel. There are noticeable rooting differences between varieties.

The concentration of ammonium-nitrogen is kept to a minimum. Sodium and chloride accumulation is an issue.

Figure 15. Use of hydrogen peroxide in nutrient mixing tanks

Sonneveld *et al*. (1999) examined the salt tolerance of flower crops grown in soilless culture and stated that the flower production of bouvardia was specifically decreased by the addition of sodium. Conversely, the highest EC of 4,200 μS per cm did not affect the production level of aster but did hinder the crop re-growth after the first harvest, especially when the EC was increased with sodium chloride.

Katsoulas and Voogt (2014) reviewed recent trends in salinity control for soilless growing system management. Soilless cultivation, especially with drainwater recirculation, has great potential for water saving. However, accumulation of unwanted ions in the root environment and drainwater, such as sodium, chloride and sulphate, constrains the potential for complete recirculation. Desalination of poor quality irrigation water represents one method for improvement of hydroponic drainwater recirculation potential.

There are also iron availability problems, especially as hydrogen peroxide readily oxidises iron. The solution pH is kept at 5.6 and the EC concentration at 1,700 μS per cm.

According to Sakamoto *et al*. (2001), a higher quality of chrysanthemum can be produced in wet-sheet culture, using a non-woven fabric, than in deep-flow technique.

Moustafa and Morgan (1983) studied the response of spray chrysanthemums to a range of nutrient solution concentrations in NFT. Root initiation and development was found to be satisfactory at approximately 650 μS per cm. During the long-day vegetative growth phase, dry weight of root and shoot portions was maximised at approximately 2,000 μS per cm.

Plant height, fresh weight and number of short days to harvest were significantly reduced at the highest solution concentration (3,900 µS per cm), while stem strength was improved. Overall growth and cut flower quality was optimal at approximately 2,000 µS per cm.

Ehret *et al*. (2005) compared the growth of roses in open drainage culture and a nutrient recirculation system. Recirculation had no effect on harvest parameters during the first eight weeks of the harvest period but had a negative influence on stem length during the second eight week period. Leaf chlorosis was observed in all recirculation treatments.

Voogt and Sonneveld (2009) examined the effects of iron chelate type and pH on substrate-grown roses. The appearance of leaf chlorosis indicated problems with iron and manganese uptake and was related to yield reduction. Iron chelates, such as Fe-DTPA and Fe-EDDHA, are commonly used as treatments. In the tests, iron uptake was clearly affected by the pH with both chelate types. It was concluded that an optimal pH control was the best method of preventing chlorosis. The choice of the chelate type was less effective and could enhance manganese deficiency. It is also important to use accurate dosing and monitoring equipment, as mistakes may easily occur (Figure 16). According to Marschner (1995), manganese toxicity symptoms may appear as leaf interveinal chlorosis and necrosis, in many instances.

Figure 16. Manganese toxicity caused by inaccurate nutrient dosing

Grower Visit to Karel Bolbloemen B.V., Bovenkarspel: 24 April, 2014

This family business has 75 hectares of tulip bulbs and produces approximately 50 million tulip stems from forcing bulbs, in a very intensive operation involving solution hydroponics (Figures 17 and 18).

Figure 17. Tulip bulbs in crates at Karel Bolbloemen B.V.

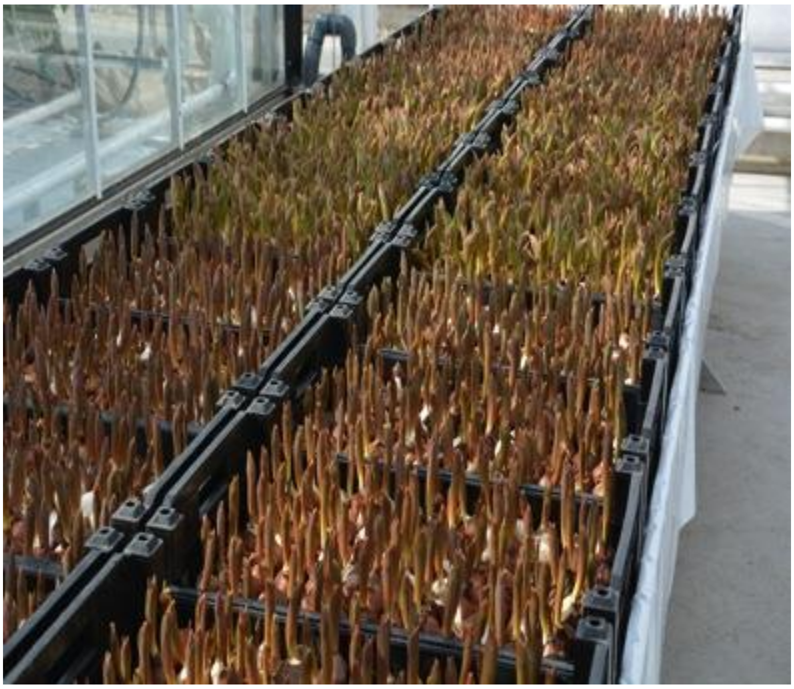

Figure 18. Tulip bulbs in solution hydroponics

The tulip bulbs are positioned upright in forcing crates and are irrigated with a dilute solution of calcium nitrate or calcium chloride. A solution EC of 1,800 to 2,000 µS per cm is used during the rooting phase and, whilst under glass, an EC of 1,500 to 1,800 µS per cm is maintained in the applied solution and rootzone (Figures 19 and 20).

Figure 19. Tulip bulbs being forced under glass in solution hydroponics

If the EC is allowed to rise above 3,000 µS per cm, this will result in shorter tulip stems.

Nelson and Niedziela Jr. (1998) found that *Tulipa gesneriana* forced hydroponically in distilled water developed calcium deficiency symptoms, including topple and flower bud abortion. Prevention of calcium deficiency and uptake of calcium was greater when calcium was supplied in the nitrate form, rather than as chloride or sulphate. Calcium deficiency could not be prevented at a high temperature regime of 22°C day and 18°C night.

Figure 20. Fertigation rig for tulip bulbs in crates

Proeftuin Zwaagdijk, Zwaagdijk-Oost

The Proeftuin Zwaagdijk has a nationwide network, with locations in North Holland and in the Westland, plus trials fields at 100 locations spread over the whole of the Netherlands (from Limburg to Groningen). Proeftuin Zwaagdijk offers near-market, practical research on a variety of subjects, such as LED lighting and the use of solution hydroponics for glasshouse and outdoor cropping.

The experimental horticultural station in Zwaagdijk started in 1986. From 1990 onwards, the government reduced funding for practical research and, as a result, agricultural research was radically changed nationwide.

Proeftuin Zwaagdijk was to be closed due to this reorganisation. However, the governing body of Proeftuin Zwaagdijk decided to continue from 1st January 1997 as an independent, private foundation. The business has already greatly developed and has established its place as a research and information centre in Holland (Figure 21).

Figure 21. Proeftuin Zwaagdijk logo

Current areas of work include: field vegetables; arable crops; bulbs and bulb flowers; herbs; glasshouse vegetables; and protected flower crops (Figure 22).

Figure 22. Onions in solution hydroponics under glass

In terms of the solution hydroponic work, trials with forcing tulips using this technique started in 2000. Now, it is thought that 80% of tulip growers are using solution hydroponics for forcing.

The main reasons for having to consider moving from soil production to hydroponics include problems with a range of soil diseases, such as *Fusarium* species and a requirement for improved control over plant nutrition.

Other flowers have been recently tested using hydroponics, including *Phlox* species involving plants on floating polystyrene rafts, *Callistephus chinensis* and *Aconitum* species (Figures 23 and 24). Reference to an unspecified Government report, in preparation, was made at the time of the visit.

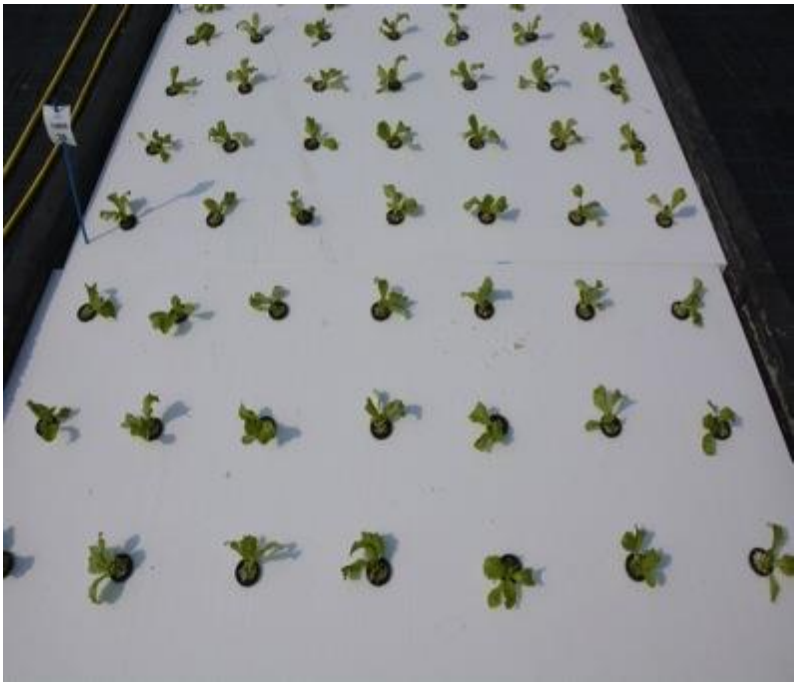

Figure 23. Outdoor lettuce in solution hydroponics

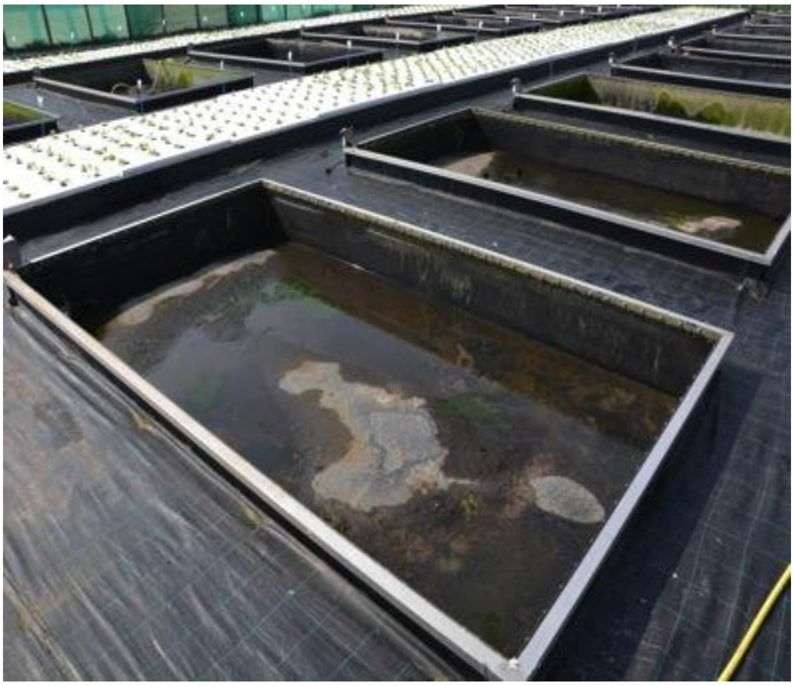

Figure 24. Outdoor solution hydroponic cropping beds

Visit to Proeftuin Zwaagdijk: Hydroponics Symposium on 24 September, 2014

A return visit to Proeftuin Zwaagdijk, to attend a symposium on hydroponics and view progress with the outdoor hydroponic production systems, was also completed on 24 September, 2014.

Matthijs Blind presented the background to trials involving outdoor hydroponic production of lettuce. The investigations started in 2007 with separate NFT channels for the cultivation of lettuce plants. In 2008, the work progressed to include DWC (Deep Water Culture) or DFT (Deep Flow Technique), which reduced the risk of growth being disturbed by windy weather conditions and provided opportunities for further automation of the crop production process.

In 2009 and 2010, tests were extended to ascertain the suitability of such outdoor systems for the cultivation of leafy vegetables, leeks and summer flower crops. The Dutch Ministry of Agriculture and the Horticultural Board financed the project work in The Netherlands, in conjunction with Wageningen University/PPO and Proeftuin Zwaagdijk. Cultivation Systems B.V. was the first commercial producer of floating systems ('Dry Hydroponics') in The Netherlands.

DWC systems consist of basins or water reservoirs, which are between 10 and 35cm in depth and constructed with or without active aeration and nutrient recirculation (Figure 25). The young plants are positioned in floats, consisting of plastic cones or holders, and the roots are then allowed to develop in the water under the plant holders (Figure 26). As with substrate hydroponics, nutrient dosing, pH and EC monitoring equipment is essential to maintain the correct pH and nutrient balance in the irrigation water (Figure 28).

Lettuce, endive, radicchio, wild rocket, corn salad, spinach, Chinese cabbage, paksoi, oxheart cabbage, broccoli, leek, bunching onion, fennel, celeriac, mint, coriander and lemon balm have been successfully grown in trials involving DWC systems (Figures 27 and 30).

In addition, summer flower crops and perennial flowers have also been grown in the DWC systems, such as sunflowers, Solidago, Hemerocallis, Echinops, Veronica, Paeonia, Chelone, Hosta, Echinacea and Astilbe.

However, Phlox, Aconitum, Callistephus, Delphinium, cauliflower and parsley were considered more difficult to grow in DWC systems (Figure 29).

For most crops, a solution pH range of 5.5 to 6.0 and an EC of 2.0 mS per cm were considered to be satisfactory for normal plant growth and development (see also Table 5).

Nutrient solution aeration was shown to increase production of most crops and is an essential component of any solution hydroponic system.

It was possible for lettuce and endive to be produced for three years using the same nutrient solution (up to 10 crop cycles), with no decline in plant development or yield.

The maximum daily temperature difference measured in the basins was 1-2°C and, during spring, the increase in temperature of the nutrient solution had a positive effect on the production and length of the cropping cycle.

In general, the pathogenic risk did not appear to be higher in DWC hydroponics, except that lettuce seemed to be more susceptible to the fungus *Microdochium panattonianum* (anthracnose) in the DWC system compared with soil.

Figure 25. Lettuce trials in solution hydroponics

Figure 26. Lettuce rooting in solution hydroponics

Figure 27. Lettuce Lollo Rossa ‘Cavernet’ in solution hydroponics

Figure 28. Irrigation control rig for solution hydroponics

Figure 29. Callistephus chinensis in solution hydroponics

Figure 30. Coriander in solution hydroponics

Specific Solution Hydroponic Systems Suitable for Flowers

As mentioned above, the technique known as ‘Dry Hydroponics’ is a cultivation method suitable for short duration crops. This system was developed in an attempt to reduce root disease development in lettuce crops and also to produce the best quality product. The float and holder are constructed so that the base of the plant is kept drier and air roots are able to develop above the main hydroponic water line.

Maurice van der Knaap presented information on ‘Dry Hydroponics’ at Proeftuin Zwaagdijk, which included claims of higher lettuce dry matter, when compared with crops produced in soil and other hydroponic systems. In addition, there were hardly any issues with root diseases and less lettuce tip burn. It was emphasized that continuous oxygenation of the hydroponic solution is very important for the success of the system. Further automation, especially with regard to plant spacing and harvesting, is also possible with this system.

Jan Botman of Botman Hydroponics B.V. demonstrated an advanced outdoor solution hydroponics system, which may also have possibilities for the cultivation of cut flower crops under protection in UK (Figure 31). The crop production platform consists of a UV resistant, hard plastic float, rather than a polystyrene float (Figure 32). Plants are propagated in a dense coir substrate plug, for example, which is inserted into a plastic holder. This holder is then placed over the pre-formed conical part of the plastic float and rooting continues to develop in the hydroponic solution below (Figures 33 and 34).

This system would appear to be suitable for production of flower crops under glasshouses and polythene tunnels in the UK. Sandwich panels may be used to construct the basins and water temperature control would be more easily controlled under protection. There would also appear to be opportunities to automate the spacing and harvesting operations involved, as with the ‘Dry Hydroponics’ system.

It was also claimed that the Botman Hydroponics system may also be suitable for the cultivation of chrysanthemum, alstroemeria and freesia crops.

Figure 31. Lisianthus in Botman Hydroponics

Figure 32. Lettuce variety trials in Botman Hydroponics

Figure 33. Lettuce plants in Botman Hydroponics holders

Figure 34. Fennel plants in Botman Hydroponics

GreenQ Improvement Centre, Bleiswijk

Glasshouse trial compartment 5 of the GreenQ Improvement Centre was recently refurbished by the glasshouse building company Certhon, involving conversion of 1,008 m^2 to a pre-formed cassette substrate bed for the culture of *Lisianthus russellianum (Eustoma russellianum)* ‘Piccolo White’ in coir.

The main purpose of the trial is to establish how to grow the lisianthus crop out of the soil, whilst attempting to save 35% on energy inputs, 90% on fungicides and reducing overall drainwater emissions.

The cultivation system was designed by Floor van Schaik and consists of a concertinaed metal wire rack, which is lined with woven matting (Figure 35). This material holds the coir but allows water to be absorbed by the substrate via an Erfgoed ebb and flood floor (Figures 36 and 37).

As a direct consequence of the ebb and flood system, it is possible for the plant roots to grow through the matting and into the glasshouse floor soil. Although the soil has been steam sterilized, the risk of disease transfer from the soil to the crop would appear to be increased with this technique. In addition, the requirement for steam sterilization would appear to constitute an additional operation, prior to installation of the hydroponic system. The construction of a self-contained hydroponic system would offer a reduction in contamination from direct contact with soil and allow precise control over nutritional factors.

The compartment has also been fitted with diffuse glass and a dehumidification system.

In line with the above trial, a group of stakeholders from the Dutch Lisianthus sector have recently discussed a new system approach for a more sustainable greenhouse production of lisianthus at Wageningen UR.

Energy consumption, calculated using the KASPRO energy model, was used to provide the following information. By growing in artificial substrates, the energy required for soil sterilization (20m^3 m^{-2} natural gas equivalent) may be reduced.

Heat consumption in the crop (42m^3 m^{-2} n.g.e.) may be decreased by more use of multiple energy saving screens and less use of a minimal heating (water temperature) level.

For the prevention of problematic relative humidity levels in the greenhouse, a system to dehydrate the air with dry air is required and this could save 17.8m^3 m^{-2} n.g.e.

If all suggested ideas for energy savings could be implemented, than it may be possible to achieve a reduction of 55m^3 m^{-2} n.g.e.

Figure 35. Floor van Schaik rack substrate system

Figure 36. GreenQ lisianthus hydroponic trial 2014

Figure 37. GreenQ lisianthus cropping beds

In addition to the ground rack system, there are different methods of substrate containerisation, which may be suitable for UK hydroponic cut flower production. The experimental work on Jersey included the use of five litre capacity black polypropylene pots, which were irrigated by existing drip tube and peg systems. On detection of disease problems, individual pots could be removed or replaced, in a similar way to slab substrate systems.

Pre-formed growing gutters may also be suitable for cut flower production (Figures 41 and 42). There is a range of designs, including separate channels to allow the collection of drainwater for nutrient recirculation (Figure 42). As the pre-formed gutters are constructed on site, this would appear to offer flexibility for the accommodation of different crops in a single glasshouse block, or a range of crops in different growing structures.

The Futagrow project at the Demokwekerij in Honselersdijk (Figures 43 and 44) provides an indication of how to maximise crop production within a glasshouse, by incorporating movable crop gutters. Continuous production is achieved by establishing the new crop at high level in the glasshouse, whilst harvesting at the lower level. The tomato crop shown in Figures 43 and 44 is being grown in a closed crop gutter and receiving liquid nutrient feed via a drip irrigation system. The root system develops along capillary matting and the drainwater is collected in a separate channel (Figures 42 and 43).

UK

To date, individual growers have tested the use of loose coir and also proprietary coir slabs for the production of annual cut flowers, such as column stocks (*Matthiola incana*) and statice (*Statice sinuata*) (Figure 38).

Figure 38. Cut flower rooting in coir slabs

Stocks in Coir

Loose coir has been tested in containers and crates – initial problems have included high pH and variable moisture control, resulting in iron and manganese leaf chlorosis symptoms (Figure 39).

Sonneveld and Voogt (1997) found that lowering pH in rockwool slabs suppressed leaf chlorosis in two varieties of *Gerbera jamesonii* (pH range of 6.7 to 5.6). Increasing the manganese concentration in the input feed also reduced the manganese deficiency symptoms. The pH strongly affected the number of flowers harvested and also the flower weight. It was concluded that the effect of pH on the trace element absorption by the plants was substantial. It should also be noted that the manganese concentrations in the plant tissues were closely correlated with those in the rockwool slabs.

Savvas *et al*. (2003) found that a high rootzone pH restricted the manganese, zinc and copper uptake, as indicated by both analytical results and plant visual symptoms in a gerbera crop grown in pumice. The results indicated that gerbera is prone to manganese and copper deficiencies at pH levels above 6.0 in the rhizosphere.

Figure 39. Manganese deficiency in stocks caused by high coir pH

Savvas and Gizas (2002) reported that gerbera leaf phosphorus, iron and manganese concentrations were reduced by high rootzone pH in a pumice drainwater recirculation system. They also found that both the number of flowers per plant and the flower stem length were significantly lower in all recirculation treatments, compared to those obtained when the drainwater was discharged.

Savvas *et al*. (2002) also discovered that the inclusion of silicon (water soluble potassium silicate) in the nutrient solution resulted in a significantly higher proportion of Class I gerbera flowers and a noticeably larger stem diameter.

In addition, control of the UK trial coir EC concentration and main element balance has been difficult to achieve, over the last two years, in the absence of accurate nutrient dosing equipment and monitoring.

A move to buffered coir slabs, in conjunction with investment in accurate fertigation equipment, would help to improve plant establishment, subsequent growth and continuity production of quality flowers.

The use of coir propagation cubes has been tested for the production of summer flowering plants, such as Cerinthe major 'Purpurascens'. The normal growth of plants to the full flowering stage was achieved using a balanced liquid feed. Plants were cultured in the propagation blocks contained within a non-drain polypropylene tray (Figure 40).

Figure 40. Cerinthe major ‘Purpurascens’ flowering in coir blocks

Figure 41. Formflex growing gutter for lettuce

Figure 42. Futagrow Formflex gutter design

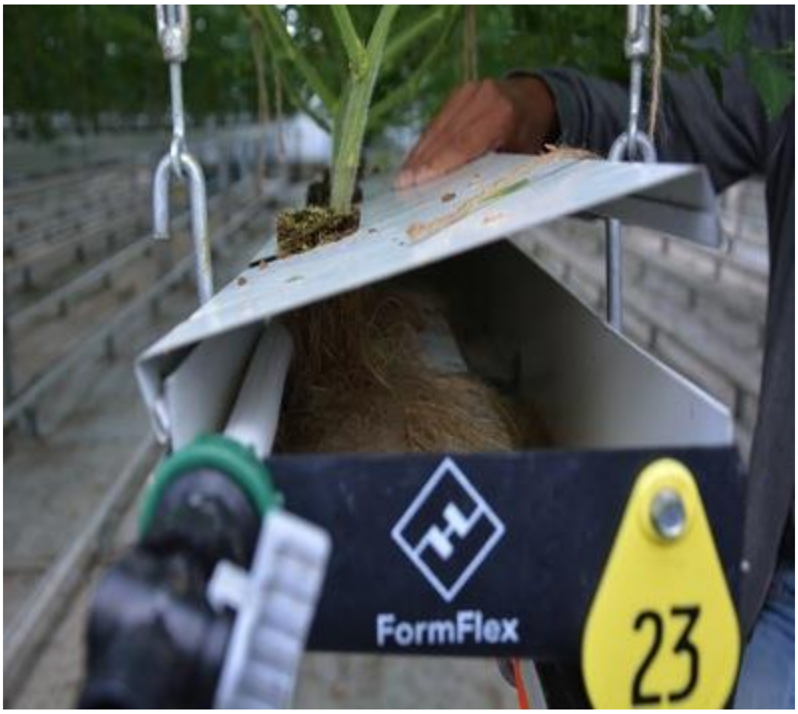

Figure 43. Futagrow Formflex gutter showing tomato roots

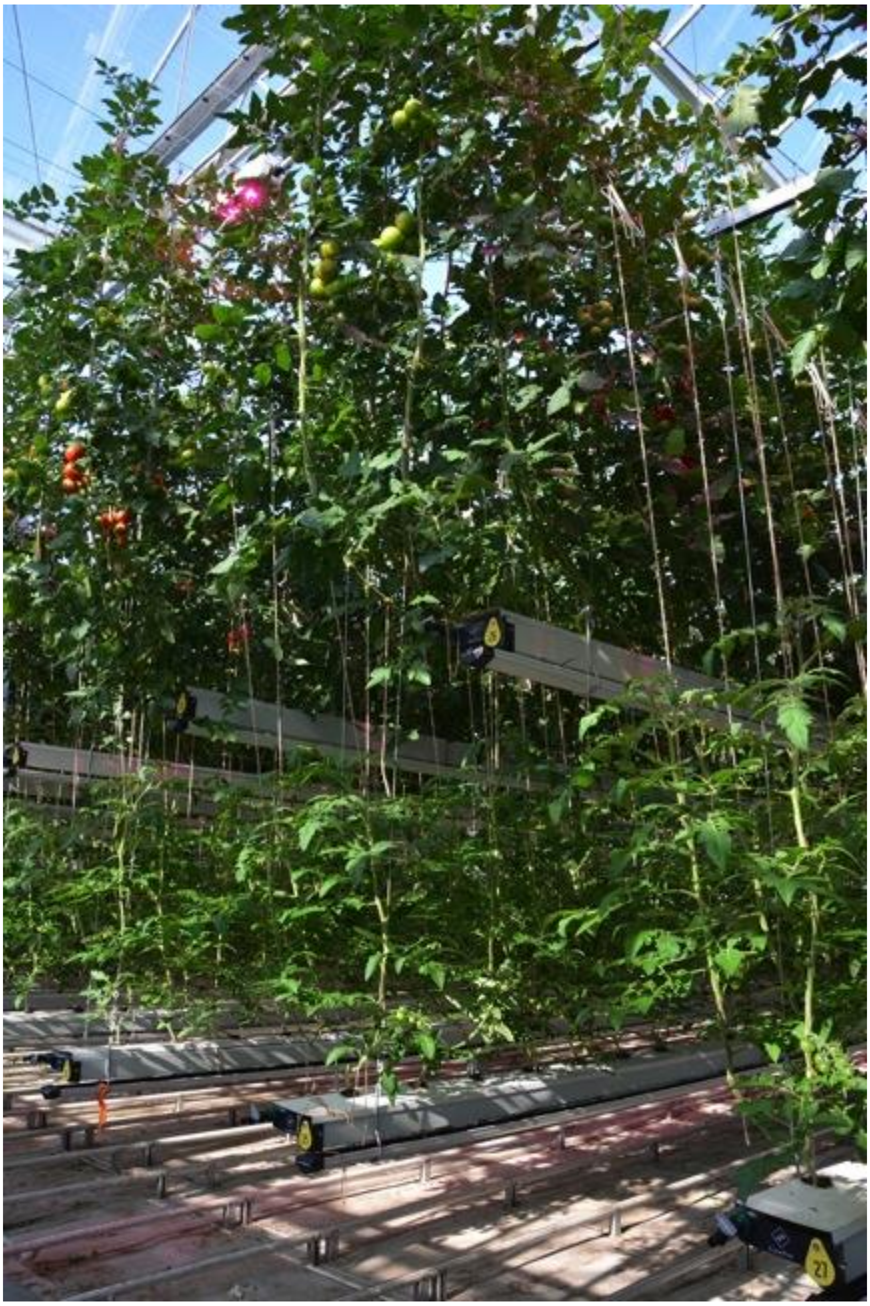

Figure 44. Futagrow multilayer cropping system

Future Intensive Growing Systems

There is much current interest in the development of intensive, multilayer crop production systems for culture of seedlings, micro-greens and leafy salad crops. One example of a prototype UK intensive cultivation unit is illustrated by the ‘Growing Underground’ project at the Deep Level Shelters, in Clapham, London (Figure 45).

Whilst the design of the growing beds is similar to the Deep Water Culture systems discussed above, the units are more intensively cropped. The attention to detail required, especially with regard to control of the environment and the hydroponic system, is paramount to the success of such intensive growing operations. Seedlings are being grown on thin layers of recycled carpet fibres (Figure 46) and substrates based on woodfibre are also being produced. These systems may also be of use for the production of short-season flower crops, either in propagation, or as intensively grown flowering plants.

Figure 45. Intensive salad leaf trials using LEDs

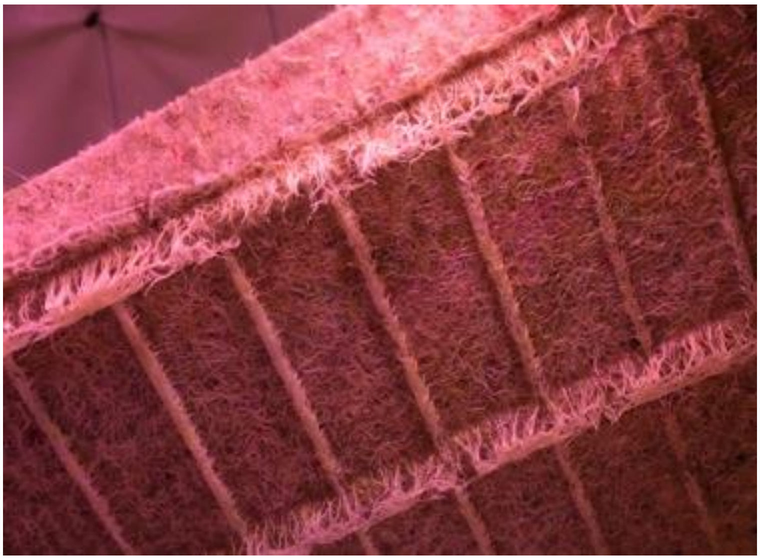

Figure 46. Seedlings rooting in recycled carpet fibres

Suggested Trials for 2015

- The development of a robust substrate hydroponic production protocol for culture of UK column stocks in coir and also solution hydroponics.
- This should include a comparison of stocks grown using coir in open containers, metal racks, gutters and also specific coir slabs.
- The suitability of existing crop support rack and growing gutter systems should be compared under UK growing conditions.
- Examination of practical solution hydroponic systems – such as Botman Hydroponics and 'Dry Hydroponics' – and their suitability for the production of UK cut flower crops, such as stocks and lisianthus.
- Comparison of other solid substrates for production of UK annual flower crops, including pumice, perlite and woodfibre products.
- The use of accurate dosing equipment and pH / EC monitoring should also form part of these trials.
- Production of reliable and specific nutrient target concentrations for input liquid feeds, rootzone and plant leaf tissue.
- Development of a strategy for recirculation of drainwater from UK cut flower production systems, involving both solution hydroponics and substrate hydroponics.

Conclusions

- The use of hydroponics for the production of quality UK cut flower crops is currently in its infancy.
- Grower knowledge of specific plant nutrient requirements for both solution and substrate hydroponics is limited.
- The use of floating solution hydroponics, crop rack support or growing gutter systems is largely untested in UK.
- Investment in accurate nutrient dosing equipment, in conjunction with pH and EC monitoring equipment, will be required for any new project involving hydroponic cut flower production.
- The use of an accredited laboratory for the accurate analysis of background water supplies, hydroponic solutions, substrate samples and plant leaf tissue will also be essential to the success of a new venture.
- The use of coir, perlite and rockwool would appear to offer the most sensible starting point for trials on growing cut flower crops in substrate hydroponic systems.
- The use of other substrate systems, using pumice and woodfibre should also be investigated.
- The outdoor solution hydroponic systems demonstrated at Proeftuin Zwaagdijk, such as Botman Hydroponics and 'Dry Hydroponics' should be further investigated and adapted for trials under protected structures in UK.
- Careful planning and installation of a system combining the use of a solution hydroponics with recirculation of the drainwater will be required to prevent problems with plant root development, disease infection and low solution oxygenation, for example.
- The use of an appropriate glasshouse cut flower trial facility, such as the Stockbridge Technology Centre and the new Reaseheath College glasshouse unit, should help to provide further knowledge transfer for growers in 2015/16.

Knowledge and Technology Transfer

HDC News article: Cut Flower Hydroponics

Cut Flower Grower Meeting at Horticulture Training Group, Spalding: Autumn, 2014

Grower Meeting at The Cut Flower Centre: Summer, 2015

South Holland Growers' Club presentation: Autumn, 2015

Promotion via The Cut Flower Centre website

Promotion via the May Barn Consultancy Ltd website

Glossary of terms

Air-filled porosity: the fraction of the bulk volume of soil or substrate that is filled with air at any given time or under a given condition, such as a specified water content or water matric potential.

Aeroponics: the cultivation of plants using a mist of dilute nutrient solution, applied to roots suspended in air.

Anaerobic Digestion: a unit process designed to biologically convert organic matter through the action of microorganisms in the absence of elemental oxygen.

Bulk Density: the total soil or substrate volume including voids, not just the individual soil or substrate particles.

Cation Exchange Capacity (CEC): how effectively a soil or substrate hosts exchanges of cations between its minerals and plant roots. In general, soils high in clay and organic matter carry a negative charge that retains plant nutrient cations against leaching away. High CEC usually correlates with high fertility.

Chlorosis: an interveinal yellowing or general mottling of leaves, caused by a lack of chlorophyll plant pigment. This is usually due to a mineral deficiency, such as magnesium, iron or manganese and results in a decrease in photosynthetic rate.

Clinoptilolite: a natural zeolite with a high cation exchange capacity, comprising a microporous arrangement of silica and aluminium tetrahedra.

Digestate: The solid product of anaerobic digestion, which also produces biogas.

Drainwater: excess water containing nutrients, which forms during drainage of applied irrigation liquid through the growing medium.

EC (electrical conductivity): Conductivity of electricity through water or an extract of soil. Commonly used to estimate the soluble salt content in solution.

pH: a measure of the hydrogen ion concentration in an aqueous solution on a scale from 1 to 14, 1.0 being extremely acidic, 14 highly alkaline and 7.0 being neutral.

Recirculation: The re-use or recycling of drainwater after it has moved through the solution hydroponic or substrate hydroponic system.

Rhizosphere: The soil, solution or substrate surrounding and directly influenced by plant roots.

Solution Hydroponics: hydroponic system using water to carry nutrients and oxygen, in the support of plant root growth, for example nutrient film technique (NFT).

Substrate Hydroponics: hydroponic system using a solid substrate to support plant roots and providing access to water, nutrients and oxygen, for example coir.

Water Holding Capacity: The amount of water held by a given quantity of absolutely dry soil or substrate when saturated.

Zeolite: Any mineral belonging to the zeolite family of minerals and synthetic compounds characterized by an aluminosilicate tetrahedral framework, ion-exchangeable large cations, and loosely held water molecules permitting reversible dehydration.

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Appendices

Appendix I

An evaluation of the use of nutrient-loaded clinoptilolite zeolite in the production of standard carnations, using only water in the irrigation programme in place of liquid feeds.

Following earlier experiments on the suitability of nutrient-loaded clinoptilolites for the production of standard carnations, this experiment aimed to examine whether the nutrient loading of the clinoptilolite would sustain a crop over a complete flower production cycle, using only water in the irrigation pulses.

Objectives

1. To assess plant growth and development characteristics of standard carnation varieties growing in nutrient-loaded clinoptilolite and using only plain water in the irrigation cycles.
2. To measure actual nutrient concentrations in the irrigation water and drainwater, to determine if there were any changes in the system nitrate-nitrogen and phosphorus concentrations, in particular.
3. To measure nutrient concentration changes in the plant leaf sap over the period of the experiment.

Materials and Methods

Cuttings of 12 standard carnation varieties were planted on 30 March, 1993 at a rate of four cuttings per five litre pot, to give a final plant density of 32 plants per square metre.

Plot size was 24 pots per variety and the experimental design incorporated two replicates of each variety in a fully randomised design. An overhead irrigation system, supplied with water only, was used to maintain an even moisture level at the surface of the nutrient-loaded clinoptilolite ('Hydrocult S') and encourage rapid rooting into the substrate during the eight week establishment phase. Thereafter, the pots were dosed with water through a drip irrigation system during the life of the crop at a rate of two litres per hour and no liquid feed was applied to the system at any time.

The first flowers were picked 16 weeks after planting (19 July) and harvesting continued for 18 months. The final pick was on 30 December, 1994.

Results

Average marketable yields were similar to those recorded in previous experiments using pumice (Anon, 1992). The standard varieties 'White Giant' and 'Master' performed in a similar manner in this experiment to earlier tests.

Timing of flower flushes was normal, with a first flush starting in July 1993 and a second season main flush starting in May 1994.

Variety performance gave a rank order, with 'White Giant' as the highest yielding (536 marketable Class I blooms per square metre), with 78% marketable.

Conclusions

- Commercially acceptable yields of high quality standard carnations were produced in this experiment with a nutrient-loaded clinoptilolite, 'Hydrocult S', using only water in the irrigation cycles.
- Fast plant establishment relied on the careful maintenance of moist conditions in the rooting zone. This was complicated by rapid drying of the substrate surface at the top of the pot. Early rooting was satisfactory but it is possible that dry substrate conditions and high initial EC concentrations in the drier zones could have impeded further root development.
  This could have been improved by increasing the proportion of fine grade clinoptilolite and, possibly, a water absorbent gel or proportion of bentonite clay in the substrate mix.
- The main nutritional limiting factor to plant growth was nitrogen and the substrate became depleted in ammonium-nitrogen by the end of the first flower flush. Subsequent production of shoots was limited by the availability of nitrogen from the substrate and from the irrigation water.
- As phosphorus is not held as a cation within the clinoptilolite matrix, an initial release of phosphorus as phosphate was expected in the first drainage flushes.
  However, the plant leaf sap analysis results indicated that there was an adequate concentration of phosphorus in the new leaf tissue and that there were no phosphorus deficiency symptoms evident in the crop canopy.

- The zeolite released potassium ions, which were readily absorbed by the plants and it is likely that an interaction with calcium and magnesium was involved in the cation exchange process.
- Sap analysis results indicated that there was a lower concentration of calcium present and this was probably more related to plant uptake from the root zone and subsequent internal plant transport under the influence of glasshouse humidity levels.
  Any cations released into the root zone later in the experiment were probably absorbed quickly by active plant roots or re-adsorbed by the clinoptilolite.
- It was noticeable that there was a low level of root and stem base disease problems over the winter period in this crop. This could have been due to a combination of dry substrate surface conditions and the lower availability of nitrogen thus preventing soft, luxuriant growth.

Appendix II

An examination of the growth and flower production of standard carnations grown on nutrient-loaded clinoptilolite irrigated with water only, compared with pumice and foam substrates, which were fertigated with liquid feeds.

Objectives

1. To obtain information on the growth and development of standard carnations on pumice and foam cylinders receiving liquid feed inputs throughout the life of the crop, compared with a nutrient-loaded clinoptilolite (‘Hydrocult F’) and a mixture of nutrient-loaded clinoptilolite (‘Hydrocult F’) and a polyacrylamide gel (‘Alcosorb 400’), receiving only water in the irrigation cycles.
2. To assess flower yield and quality.
3. To measure changes in drainwater nutrient concentration, to determine if there was less leaching of nutrients from the nutrient-loaded clinoptilolite systems, with particular reference to ammonium-nitrogen, nitrate-nitrogen and phosphorus.
4. To measure changes in plant leaf sap nutrient concentration to monitor the nutrient concentration profile of the nutrient-loaded clinoptilolite, with particular regard to leaf sap nitrate-nitrogen.
5. To measure changes in substrate nutrient concentration at the end of the experiment by using analytical methods involving acid digestion and sodium extraction techniques.

Materials and Methods

Two varieties of standard carnation cuttings (‘White Giant’ and ‘Master’) were planted into pumice, foam and nutrient-loaded clinoptilolite on 23 February, 1995. One treatment consisted of nutrient-loaded clinoptilolite plus 10% by volume of a polyacrylamide gel (‘Alcosorb 400’) at a rate of three grams per five litre pot. Each plot contained 24, five litre, black polypropylene pots per variety and a plant density of 32 plants per square metre was achieved by using four cuttings per pot.

The pumice and foam pots were irrigated with nutrient-balanced liquid feeds and the nutrient-loaded plots were irrigated, using a separate irrigation system, with water only over the 22-month growing period.

The first flowers were picked four months after planting and harvesting was performed three times each week until the final harvest on 31 December, 1996.

Results

The flower yield pattern over the 18-month production period was similar for the two varieties growing on each substrate, with a major flush of flowers in July 1995 and also over the period June to August, 1996 inclusive. These two major production periods were interspersed with smaller flushes of flowers in November 1995, February 1996 and December 1996.

Initially, flower yields were similar from both varieties in all of the treatments. Following the first flower flush, however, the production of side shoots from plants in the nutrient-loaded clinoptilolites was visibly slower and weaker than in pumice. This resulted in a lower number of Class I flower stems being produced in the nutrient-loaded clinoptilolite treatments, especially over the period covering June to August, 1996.

Mean cumulative Class I yields were highest for both ‘White Giant’ and ‘Master’ in pumice at 755 and 624 blooms per square metre, respectively, to the end of December, 1996.

In comparison, the mean cumulative Class I yields for ‘White Giant’ and ‘Master’ in nutrient-loaded clinoptilolite were 564 blooms per square metre (25.3% lower than on pumice) and 464 blooms per square metre (25.6 % lower than on pumice), respectively, to the end of December, 1996.

Conclusions

- The nutrient-loaded clinoptilolite substrate loadings of ammonium-nitrogen and phosphorus were the main nutritional limiting factors affecting plant growth and flower yield.
- Drainwater nutrient concentrations were low throughout the experiment from the nutrient-loaded clinoptilolite plots, whilst drainwater from the fertigated pumice plots contained notably higher concentrations of nitrate-nitrogen, phosphorus and potassium.
- Leaf tissue analysis in 1996 revealed lower total nitrogen and total phosphorus concentrations in leaves sampled from plants growing in nutrient-loaded clinoptilolite.
- The clinoptilolite cation exchange mechanism involved potassium, calcium, magnesium and sodium as the major participating ions. The clinoptilolite total potassium concentration decreased and the total calcium, magnesium and sodium concentrations increased over the experimental period. The clinoptilolite total

phosphorus concentration decreased during the experiment and the release of phosphorus could have been related to and regulated by the accumulation of calcium in the substrate.

- It is clear that loading of ammonium-nitrogen in nutrient-loaded clinoptilolite is sufficient to produce commercially acceptable yields of standard carnations over an eight-month period. Therefore, in order to compete with flower production from a fertigated pumice crop, it would be necessary to supplement the nitrogen and, possibly, the phosphorus contents of the nutrient-loaded zeolite by the introduction of a liquid feed of ammonium nitrate or mono-ammonium phosphate, for example. Careful nutritional monitoring of the system would be required, however, as the introduction of NH_4^+ into the root zone would tend to decrease the pH by release of H^+ ions and also encourage cation exchange with the clinoptilolite, with the possible release of high concentrations of accumulated sodium ions.
- Future work should examine higher loading start values of nutrient-loaded clinoptilolite and the supplementation of nitrogen by the addition of liquid feeds containing ammonium-nitrogen. Liquid feeding frequency and control of the concentration of the applied supplementary feed would also be additional areas of research on which to focus.

