FINAL
PROJECT REPORT
for
PC 250

To:

Horticultural Development Council
Bradbourne House
East Malling
KENT
ME19 6DZ

Protected lettuce: A feasibility study to investigate the economics of sustainable lettuce production in hydroponics

May 2006

Project Summary

PC 250

Protected lettuce: A feasibility study to investigate the economics of sustainable lettuce production in hydroponics.

Final Report : May 2006

Title:	Protected lettuce: A feasibility study to investigate the economics of sustainable lettuce production in hydroponics.
Report:	Final report, May 2006
Project Number:	PC 250
Project Leader:	Dr G M McPherson Director – Plant Pathology Stockbridge Technology Centre Ltd Cawood, Selby North Yorkshire, YO8 3TZ Tel. 01757 268275 Fax. 01757 268996 martinmcpherson@stc-nyorks.co.uk
HDC Project Co-ordinator:	Mr G Smith, Mapleton Growers, Essex
Location:	Stockbridge Technology Centre Ltd Cawood, Selby, North Yorkshire, YO8 3TZ Tel. 01757 268275, Fax. 01757 268996
Start Date:	1st December 2005
Completion Date:	12th May 2006
Keywords:	Salad crops, Herbs, Lettuce, Chives, Salad Onions, Ornamentals, floating hydroponic platforms, soil-grown, technology transfer, implementation, feasibility study, pesticide residues, pesticide minimisation, hi-tech, mechanised, disease control, *Rhizoctonia*, *Sclerotinia*, *Botrytis*, *Bremia*.

CONTENTS

	Page
Grower Summary	**5**
Science Section	**9**
Background	**10**
Objectives	**11**
Principal Findings	**12**
Literature review	12
Study tour to Israel	14
Location of the Pilot Facility	18
Summary of the Technologies Required	19
Potential Contributors	20
Supply & Installation of Equipment	20
Installation Schedule	20
Project Steering Group	20
Scientific Records	20
Total Costs over 3 years	22
Summary Costs	22
Additional Benefits of this Study	21
Conclusions	**23**
Technology Transfer	**24**
References	**25**
Acknowledgements	**28**
Appendices	**29**

Grower Summary

Headline

A study tour visit to the Organitech facility in Haifa, Israel in early December 2005, to observe floating hydroponics technology first hand, is a first step to determining the feasibility of the whole concept with a view to establishing a demonstration unit for the industry. The concept offers considerable advantages relative to the current soil-grown cropping systems in the UK with potential to resolve a large number of the current problems with conventionally grown crops such as lettuce.

Background and expected deliverables

The protected salad crops industry, especially lettuce, in the UK is facing a number of important issues relating specifically to pesticide residues, nitrates and the potential for food-borne microbial contamination. For soil-grown crops there is no immediate solution to some, if not all these problems, and it is considered that the situation will not improve unless alternative 'radical' solutions are considered. In this respect, especially as most of the problems arise because the crop is in effect an intensive soil-grown mono-culture, an obvious solution is to move out of the soil into some form of hydroponic production. There are already a few lettuce growers using NFT systems in the UK, one of the primary advantages being that they are less labour intensive compared to soil-grown crops. However, they are potentially vulnerable to root infection & subsequent crop loss. A novel floating hydroponics system has recently been developed which could potentially not only resolve many of the industries current problems but also reduce labour and energy costs further also. Evidence to date suggests that root health is much improved using the new technology. The technology is not only applicable to lettuce but also to other crops such as herbs, salad onions, Chinese vegetables & potentially some ornamental crops.

This report presents the results of an initial feasibility project which has examined the potential for establishing a 'state-of-the-art' development and technology transfer facility for the UK salad crop, herb & ornamental industry and subsequently managing/operating it over a 3 year period; the aim being to evaluate a novel floating hydroponic technology arising from R&D in Israel and elsewhere. The primary objective will be to grow year round crops and to compare this with equivalent conventional soil or similar crops under glass in terms of practicality, crop quality & yield and economics. During this evaluation period growers will have ample opportunity to visit the site and gain first-hand experience of the technology. In addition, it is envisaged that additional funding through the DEFRA Vocational Training Scheme will provide an opportunity for personnel and growers to be trained in the operation of the floating hydroponic platforms.

Dr G M McPherson, STC Ltd & Mr G Smith, Mapleton growers & HDC Protected Crops Panel representative visited Organitech Ltd in Haifa, Israel in early December 2005 to investigate the floating hydroponics technology first hand. This visit was very successful and it is evident that the floating hydroponics technology does indeed offer considerable advantages relative to the current soil-grown cropping systems in the UK. The technology clearly has the potential to resolve a large number of the current problems with some of the conventional soil-grown crops such as lettuce e.g. pesticide residues (including MeBr issues), nitrates & food-borne microbes and it requires a thorough detailed evaluation under UK growing conditions.

A suitable 1,000m^2 glasshouse has been identified at STC Ltd in North Yorkshire and the site meets the requirements of the UK horticultural industry. Organitech Ltd, Haifa, Israel has agreed to supply and fit the equipment needed and also to provide consultancy expertise, as required, to assist in a rapid start-up of the project. Mr A Levinsohn, UK representative for Organitech Ltd will also be available in this respect also.

On the basis of the conclusions from the feasibility study outlined here and, following agreement in principal to move to the next stage, a full proposal will be for the next HDC Protected Crops Panel meeting.

Summary of the project and main conclusions

- An initial desk study, but including a brief 'study tour' to Israel to evaluate the floating hydroponics technology first-hand, has successfully concluded that it would be appropriate to establish a 'state-of-the-art' hi-tech hydroponic production facility using a novel floating crop production system for the UK glasshouse salad, and other, crops industry.

- It is evident from the literature that scientific information on deep water 'floating hydroponic' systems is very limited and that most of the available information relates to hydroponic substrate systems (open or closed) or conventional NFT techniques following the original development by Cooper *et al* in the 1970's. What published information that is available relating to this novel technology is predominantly commercial, linked to companies web-sites aimed at marketing the technology to the industry. One exception to this is work conducted by Cornell University's Controlled Environment Agriculture (CEA) Program with financial support from NASA. Encouragingly, there is considerable interest in developing similar technology in the UK and indeed a few companies have started to make significant commercial investments in this area. As such commercial information from such developments will not be readily available it is appropriate, with HDC funding, to develop an experimental 'demonstration' facility to enable information on the technology to be readily available to growers should they wish to adopt the technology in some form or another.

- The initial feasibility study therefore supports the establishment of a floating hydroponic demonstration system to evaluate the latest technology available to growers by growing year-round lettuce, herbs and other relevant crops over a 3-year period as efficiently as possible, thereby maximising labour and other inputs into the crop. It will provide an opportunity to compare any inherent advantages or disadvantages of such a hi-tech system relative to conventional soil production systems. It will also permit a detailed economic evaluation to be undertaken during this 'pilot' study period.

- A suitable modern 1000m^2 glasshouse has been identified at STC Ltd and both the glasshouse and the site fully meet the criteria needed for such a project. Organitech Ltd, Haifa, Israel have agreed to be a partner in the project and will contribute financially by providing both equipment and expertise. This will enable the glasshouse to be fitted with a series of floating hydroponic platforms, polystyrene growing units, reverse osmosis unit, nutrient supply and other relevant 'know-how'. Provision has been made for the technical and logistical management of equipment installation.

- It has been estimated that the total set-up costs for the project will be £70,625 of which £50,000 will be contributed by Organitech Ltd through provision and installation of essential equipment. This leaves a balance of £20,625 which will need to be funded from HDC at the current time. The intention would be to divide this over the 3 year period of the project.

- The annual running costs have been calculated and adjusted to allow for produce income (based on a unit price of 10p/head) and estimated contributions from partners in the project. The budgets include the cost of propagation, and any modifications thereof, planting, trial design, crop management, scientific and commercial assessment and harvesting/marketing. On this basis, the net running costs for the project in year 1 will be £93,415. Of this, £8,350 will be contributed by commercial/industrial partners, £20,000 through a marketing grant and £7, 325 through the DEFRA Vocational Training Scheme and an estimated produce income of £10,000 leaving a balance of £47,740 to be funded from additional sources. In Year two this figure would be £51,490 and in Year 3 £56,570.

- It is envisaged that the project will be overseen by a Project Steering Group comprising members of the Lettuce Technology Group and commercial/industrial partners and will be managed on a day to day basis by an experienced Project Administrator at STC Ltd.

- Funding for the main project to conduct a scientific evaluation of the floating hydroponics technology over a 3-year period will be sought from the Horticultural Development Council (HDC) as this is a near-market development or demonstration project. It is anticipated that there may be a need for additional scientific study once the facility is established and, where appropriate, separate project proposals will be formulated and submitted to relevant funding bodies/agencies.

- Additional funding will be sought via the DEFRA Vocational Training Scheme to undertake a training of relevant personnel and interested growers in the technology relative to conventional soil-grown production systems. It is estimated that a training budget of £34,415 would be required over the 3 year project term for this aspect.

- A further marketing grant will be sought to establish the salad crops produced via the floating hydroponic technology as novel with a price premium due to their freedom from pesticide residues, nitrates and microbial contamination. A figure of £25,000 has been estimated in this respect.

- This feasibility study has demonstrated that the project can be achieved with annual cash contributions from the HDC, DEFRA and the RDA of approximately £58,000[1], £8,000 and £11,000 respectively in each of years 1, 2 and 3.

Financial Benefits

Hi-Tech Floating Hydroponics Technology would create:

- A significant reduction in soil-borne disease (and pest) problems
- An improved aerial environment less conducive to infection by foliar pathogens and colonisation by pest species
- A minimised need for application of plant protection products
- A significant reduction in pesticide residues at harvest
- A reduced risk of 'naming & shaming' of growers and/or their customers

[1] This figure includes a component for initial establishment costs (approx. £6,500) spread over each of the 3 years of the project.

- Improved customer relationships, especially major multiples
- Reduced labour costs through increased mechanisation
- Increased yield through a significantly higher output relative to soil-grown crops
- More efficient use of energy through insulation and control of solution temperature
- A more predictable control of nitrate levels in crops relative to soil
- Maintenance and potential increase of market share
- A potential withdrawal from continued enforcement monitoring through the PRC
- A potentially improved cost-benefit relative to crops grown in the soil

Action points for growers

This study tour was a first step to determine the feasibility of the whole concept of developing a hydroponic technology transfer facility for the protected salads and ornamentals industry in the UK. Assuming that this idea progresses then while the initial focus of the work will primarily be on protected lettuce other high value salad crops such as herbs e.g. chives can also be evaluated. It is anticipated that once a facility is established it will provide a valuable resource to investigate other aspects of production to assist in providing an effective 'due diligence' defence to customers.

SCIENCE SECTION

Introduction

The protected salad crops industry, especially lettuce, in the UK is facing a number of important issues relating specifically to pesticide residues, nitrates and the potential for food-borne microbial contamination. For soil-grown crops there is no immediate solution to some, if not all these problems, and it is considered that the situation will not improve unless alternative 'radical' solutions are considered. In this respect, especially as most of the problems arise because the crop is in effect an intensive soil-grown mono-culture, an obvious solution is to move out of the soil into some form of hydroponic production. There are already a few lettuce growers using NFT systems in the UK, one of the primary advantages being that they are less labour intensive compared to soil-grown crops. However, they are potentially vulnerable to root infection & subsequent crop loss. A novel floating hydroponics system has recently been developed which could potentially not only resolve many of the industries current problems but also reduce labour and energy costs further also. Evidence to date suggests that root health is much improved using the new technology. The technology is not only applicable to lettuce but also to other crops such as herbs, salad onions, Chinese vegetables & potentially some ornamental crops.

This report presents the results of an initial feasibility project which has examined the potential for establishing a 'state-of-the-art' development and technology transfer facility for the UK salad crop, herb & ornamental industry and subsequently managing/operating it over a 3 year period; the aim being to evaluate a novel floating hydroponic technology arising from R&D in Israel and elsewhere. The primary objective will be to grow year round crops and to compare this with equivalent conventional soil or similar crops under glass in terms of practicality, crop quality & yield and economics. During this evaluation period growers will have ample opportunity to visit the site and gain first-hand experience of the technology. In addition, it is envisaged that additional funding through the DEFRA Vocational Training Scheme will provide an opportunity for personnel and growers to be trained in the operation of the floating hydroponic platforms.

Dr G M McPherson, STC Ltd & Mr G Smith, Mapleton growers & HDC Protected Crops Panel representative visited Organitech Ltd in Haifa, Israel in early December 2005 to investigate the floating hydroponics technology first hand. This visit was very successful and it is evident that the floating hydroponics technology does indeed offer considerable advantages relative to the current soil-grown cropping systems in the UK. The technology clearly has the potential to resolve a large number of the current problems with some of the conventional soil-grown crops such as lettuce e.g. pesticide residues (including MeBr issues), nitrates & food-borne microbes and it requires a thorough detailed evaluation under UK growing conditions.

A suitable 1,000m^2 glasshouse has been identified at STC Ltd in North Yorkshire and the site meets the requirements of the UK horticultural industry. Organitech Ltd, Haifa, Israel has agreed to supply and fit the equipment needed and also to provide consultancy expertise, as required, to assist in a rapid start-up of the project. Mr A Levinsohn, UK representative for Organitech Ltd will also be available in this respect also.

On the basis of the conclusions from the feasibility study outlined here and, following agreement in principal to move to the next stage, a full proposal will be for the next HDC Protected Crops Panel meeting.

Background

It is vital that the UK protected salads industry becomes more efficient and environmentally aware if it is to survive. For example, the future of conventional glasshouse UK lettuce production in the soil is currently uncertain due to a number of factors including the presence of persistent soil- and air-borne pathogens and pests and the concomitant need for prophylactic pesticide application, high nitrate levels and the potential presence of food-borne microbes e.g. E. coli 0157.

Several years of surveillance of pesticide residues by the Pesticides Residues Committee (PRC) and the Pesticide Safety Directorate (PSD) has highlighted a particular problem with exceedance of Maximum Residue Levels (MRLs) in salad crops, but especially glasshouse lettuce, particularly those crops grown during the winter months. Seven years of enforcement monitoring in lettuce has unfortunately not brought about a significant improvement in the situation and MRL exceedances continue to be reported.

The loss of methyl bromide (MeBr) as a highly effective soil sterilant is likely to exacerbate the problem in the next few years. As pathogen populations in the soil rise following its withdrawal (in 2003) pesticides are likely to be relied on more heavily in the interim period to maintain effective control of diseases. The alternative products e.g. dazomet (Basamid) and steam are either less effective, not readily available to all growers or dangerous to use on Health & Safety grounds.

Without a significant reduction in residue levels of pesticides there is a risk that the major retailers, in a bid to avoid 'naming & shaming', will de-list certain crops such as glasshouse lettuce and shelf-space will be lost.

Through the Assured Produce Scheme (http://www.assuredproduce.co.uk) efforts are being made to encourage growers to reduce pesticide inputs by reducing rates and extending harvest intervals beyond that specified on the product label. Whilst this might, over time, impact on residue levels at harvest it may also reduce the effectiveness of specific products leading to higher levels of pests and disease.

It may, over time, to possible to manage both pests and pathogens in soil-grown salad crops sustainably by generating and maintaining microbially-active soils with a high level of predators and antagonists. However, research & development to investigate such biological control in protected soil-grown crops will require significant investment in R&D and our understanding of such eco-systems are incomplete at this point in time. Moreover, the registration of biological products in the UK and EU more widely is currently hampered by a series of legislative challenges and few such products are currently available for use.

In addition to the problem of pesticides concern has also increased over the last few years with respect to the health risks associated with high nitrate levels in some commodities such as lettuce, spinach & salad rocket. UK research has demonstrated that at certain times of the year it is highly likely that levels above those regarded as statutory will be breached. The UK has, to date, been successful in securing a derogation though it is anticipated that this will not be possible beyond 2008. Unlike soil-grown crops where it is difficult to control nitrate uptake, in hydroponic crops nitrate levels can be regulated successfully.

The potential for microbial contamination of salad crops is also becoming an area for concern, especially since the occurrence of E. coli 0157. It will be very difficult to

provide freedom from such microbes in soil-grown crops, especially in situations where farmyard manure or other such fertiliser is used and this is particularly pertinent to organic crops. A solution to this problem (though not for organic crops) would be to grow the crop hydroponically where there is no risk of soil or other organic contamination.

Assuming the 'status quo' is not an option and that it would take several years (5-10) to develop and validate a sustainable or biological system of crop production the only alternative solution is to move out of the soil into a hydroponic production system. Whilst such a solution may appear radical it does have the potential to resolve many of the current problems relating to pesticide residues, high nitrates and microbial contaminants of concern.

A small number of lettuce and other growers, e.g. oriental vegetables, have been using the nutrient film technique (NFT) system of crop culture successfully for a number of years and therefore the general principle of hydroponic production is well proven. The novelty here is that the NFT system would be taken to the next level using a deep water 'floating platform' system which creates the opportunity to move the crop during development to a centralised area for harvesting, thereby minimising labour costs.

The first step is to determine the feasibility of the whole concept and this has been the basis of this preliminary study. The potential of current technology with respect to deep water and/or floating hydroponics technology has been examined and evaluated with a view to establishing a 'state-of-the-art pilot plant' or demonstration unit for further investigative and implementation studies.

There are a number of different systems throughout the world, each with a slightly different design concept. It is hoped that as part of the 'pilot' study such differences can be examined and evaluated with a view to providing a 'blueprint' design for future hydroponics technology for UK growers.

It should also be noted that whilst the primary thrust of the work would be towards the production of glasshouse salad crops, particularly lettuce & herbs, the system of culture could potentially be adapted to several other crops including bedding & pot plants, flowers and other vegetable crops such as salad onions.

Objectives

The overall aim of the initial feasibility study was to determine whether it was technically, economically and practically feasible to establish a 'state- of-the-art demonstration facility' for the UK glasshouse industry utilising a deep water floating hydroponics system of crop culture.

The brief was as follows:-

To undertake a brief study tour to Organitech in Israel to view and evaluate the potential of a deep water floating hydroponic system

Subject to the success of the study tour, establish a suitable location for the 'pilot' facility

Identify the preferred lay-out taking account of technical, economic and practical efficiencies and experimental requirements

Determine the potential cost and practicality of structural changes to the facility and installation of ancillary equipment

Prepare an outline of the scientific and technical input to future work in the facility

Estimate the cost of managing and running the facility over a 3 year period

Principal findings of the study

Literature review

There is a surprising paucity of technical and scientific information relating to deep water or floating hydroponic platform systems both here in the UK and overseas…and most information available on hydroponics relates to either rockwool crops or conventional NFT systems. Where information is available relating to deep water floating platform technology it is largely web-based 'commercial' information relating to different systems and the available technical 'know-how' is not readily available.

Floating platform technology is claimed to have first been developed at the University of Arizona, USA in the late seventies and subsequently adapted commercially by Hydro-Nov Inc., Mirabel, Canada. The Hydro-Nov or Mirabel technology has subsequently been installed commercially on over 20ha in Canada, USA, Mexico & Asia. The system has also been used for public interest demonstration at the Epcot Centre in Florida. For more information relating to Mirabel & Hydro-Nov see http://www.hydronov.com/ and www.mirabel.qc.com

Cornell University's Controlled Environment Agriculture (CEA) Program has been involved in greenhouse hydroponic vegetable production research since 1991. Since early on, the goal was to develop systems to produce fresh, high-quality, pesticide-free vegetables close to market. An experimental hydroponic greenhouse system for lettuce production initially developed during 1998-99 at Rutgers is now run by Challenge Industries Inc., Ithaca, New York under the trade name of Finger Lakes Fresh. For more information see http://aesop.rutgers.edu/~horteng/floating_hydroponics.htm and http://www.fingerlakesfresh.com/

Organitech Ltd, Haifa, Israel in conjunction with the Technion and funding from the US have established a commercial deep water or 'floating hydroponic' platform system under the trade name of GrowTech™. The GrowTech(TM) 2500 product line was first presented during the European lead exhibition for state of the art agriculture and horticulture "Hortifair" in Amsterdam in November 2003. In February 2004, The company announced their first commercial sales in Europe when Van Dijk Nurseries Ltd. in Eire signed an agreement to purchase the highly advanced GrowTech™ 2500 automated hydroponics growing system. See http://www.organitech.com/index.php?goto=bep for further information.

Organitech is a pioneer and world leader in supplying of High-Tech "hydroponics growing factory" for the agriculture and life-science industries, enabling the growth of leafy vegetables and other plants in a highly economic and clean surrounding,

making optimal use of resources such as water, energy, labour and land. According to their company literature:-

"The rapidly increasing worldwide demand for green leaf, clean vegetables with extended shelf-life; moving to vegetable-based nutrition; and the need for sustainable agriculture, encourage the move out from the soil into a hydroponics production. Hydroponics cultivation is becoming a genuine, inevitable alternative for traditional soil-based cultivation in greenhouses, and is an attractive business opportunity for grower around the world."

Organitech report that they are currently in the process of deploying in Russia one of the most advanced hydroponics systems in the world. A 1.2 Hectare hydroponics greenhouse integrates the most advanced growing technologies and represents one of the highest-end "hydroponics growing factories" in the world and this is in addition to already deployed hydroponics projects in Ireland and in Israel and pilots in the US and the UK.

Backed with strong intellectual property and recognizing their hydroponics technology and the products' commercial potential Organitech make an ideal partner for further development of this technology in the UK.

There are also other companies involved in this type of technology in the UK and elsewhere e.g. Swedeponic Ltd [http://www.swedeponic.com/index.htm] together with a number of smaller independent enterprises both in the UK and overseas which in effect are hybrids of the above, modified slightly to suit local conditions and crops e.g. Cherry Farms [http://www.cherryfarms.co.uk/] one of the largest specialist producers of Chinese vegetables in the UK.

It is evident from this relatively brief literature review that deep water hydroponics has considerable potential for salad, and potentially other, crop production and there are already significant commercial developments elsewhere in the world as indicated above. Swedeponic have made some inroads into the UK and Organitech have a commercial development in Eire (the Van Dijk Nursery). It is also evident that a few growers are also developing hybrid deep water systems for lettuce production in the UK and this provides a greater level of confidence that floating platform technology is likely to be commercially viable under UK conditions providing the technology can be fully validated in an experimental 'demonstration' unit. Importantly, this approach, with appropriate funding from HDC, would allow the information from such an experimental 'demonstration' project to be available to both large & small companies interested in establishing 'floating hydroponics technology on their nursery in the future.

Study Tour to Organitech, Haifa, Israel

Following agreement with HDC, Dr G M McPherson, STC Ltd & Mr G Smith, Mapleton Growers visited Israel in early December 2005 to evaluate first-hand the Organitech floating hydroponics technology.
The itinerary was as follows:-
6th December : Overnight flight from Heathrow to Tel Aviv, Israel followed by short (1 hr) train journey to Haifa.
7th December : Arrive at Haifa and meet Mr Ashley Levinsohn, UK representative for Organitech Ltd. After a brief recovery period at the hotel Mr Levinsohn acted as our guide and drove us to Kibbutz Yagur and from there to the Technion in Haifa:-
8th December : Visit to the Newe Ya'ar Research Station, Organitech headquarters, Palram Industries Ltd (a polycarbonate factory) and, at our request, a second visit to the Lettuce crop at Kibbutz Yagur.
9th December : Flight back to the UK

Visit to Kibbutz Yagur, Haifa to study a protected lettuce installation using Organitech floating hydroponics technology. We were greeted by the nursery owner (Mr Yoav Levne), Mr Lior Hessel, then President & CEO of Organitech and two American visitors (brokers) interested in introducing the technology to growers for supplying hotels in Nevada, USA.

The structure, recently established in April 2005, was 2000m^2 in size, clad in a woven polythene material with shade screens and double doors to prevent pest entry with positive ventilation via fans. Evaporative cooling was installed and appeared effective, at this time of year at least, for maintaining a good growing regime. Crops were grown on raised benches in floating polystyrene rafts with a water depth of ca. 5 cm. We were advised that all lettuce seedlings in Israel are raised centrally by specialist propagators though, instead of using peat blocks, they use a modular system with plants raised in Perlite. The polystyrene rafts (various types & sizes available) in the Organitech system were designed to suit a tapered 'plug' plant and some development would be necessary to suit peat block raised plants (or alternatively adjust the propagation technique for UK lettuce using modules). Crops being grown were predominantly Cos lettuce though there was a small amount of Chives and Red Oak Leaf lettuce. All crops present appeared to be experimental and full commercial cropping was not yet underway due to initial 'teething' problems. The crops generally looked healthy though we did note a small amount of tip-burn, particularly on the Cos lettuce.

We finished this visit with a tour of the Kibbutz itself which was evidently highly diversified and included cattle, sheep & chicken farms, a horticultural sundries business, engineering works and even a nightclub.

See Appendix 1 for photographs of the lettuce installation at Kibbutz Yagur.

4.2.2 Visit to the Technion, Haifa (Israel Institute of Technology) for discussions with Leor Hoppelbaum and Professor Gepstein, a plant biologist who runs one of 25 research groups in his department. Discussions were wide-ranging and varied touching on genomics, proteomics and metabolomics. See http://www.technion.ac.il/ for more information.

Visit to the Newe Ya'ar Research Centre, Ramat Yishay, Haifa (an out-station of the Volcani Institute), where we met up with Eyal Horowitz from Organitech. See http://www.agri.gov.il/NeweYaar.html for more information on the site.

Dr Michael Raviv, Head of Section on Environmental Horticulture at Newe Ya'ar with a strong background in hydroponics, organic composting and disease suppression joined us for discussions and took us on a tour of the site. The site itself is evidently a development centre along similar lines to STC Ltd but with a larger staff number though with substantial government support.
Dr Raviv advised us that there were 25 research staff, 20 technical /administration staff including some 55 non-permanent employees (students etc) working on site during busy times. They have a very strong breeding programme on various crops including herbs & spices and cucurbits such as Melon. We were advised that the Galia melon was bred and developed at Newe Ya'ar. During discussions Dr Raviv stated that, in his opinion, it was possible to control soil-borne pathogens of lettuce such as *Rhizoctonia* by the inclusion of composted green waste. He believed it would take a minimum of 2-3 years to develop suppressive soils. He has also seen effective control of *Fusarium radicis-cucumerinum*[2] in cucurbits, *Clavibacter (Corynebacterium) micheganense* in tomato (from seed-borne infection) and *Fusarium* infection in Chrysanthemum using similar composted materials.

Dr Raviv had clearly been instrumental in assisting Organitech develop and refine the floating hydroponic system. We discussed the potential problem of oomycetes e.g. *Pythium & Phytophthora* spp. though he assured us that, to date at least, no problems have been seen. They currently dump the hydroponic solution occasionally (once or twice/year) to correct imbalance in the nutritional status of the solution and use chlorine to disinfect the benches at this time. Dr McPherson alerted them to his observations and hypotheses (unpublished) in hydroponic crops of cucumber & tomato where the recirculated solution appears to develop suppression to oomycete fungi, causing zoospores to encyst. There is therefore a potential risk that replacing the solution aggressively could allow mass germination of encysted zoospores and therefore the solution should either not be dumped or replenished very slowly. The use of chlorine was also questioned as it is likely to disrupt the beneficial micro-organisms that are so important in the closed system. Dr Raviv also pointed out that they use dissolved oxygen in the water and previous work at Newe Ya'ar had shown it to be very beneficial for both roses & lettuce. This led to further discussions with respect to bed length and the potential for oxygen depletion. The larger depth of water in the Organitech system and the fact that there is a constant and steady flow of solution together with a boosted oxygen level ('aeration') prevented the risk of depletion on any of the commercial systems they had installed to date.

Visit to Organitech headquarters, Haifa. Here we met with various staff from Organitech though spent much of the time with Lior Hessel & Ashley Levinsohn. We were provided with a tour of the facilities and saw a small-scale demonstration of the floating hydroponics system. Lior also explained that he had developed many different prototypes of polystyrene rafts and several versions were available to suit different crop types. However, it would also be possible to have a purpose designed tray if appropriate to suit UK conditions, providing the same basic dimension of 1.lm in length is adhered to. We were also shown a futuristic closed container unit designed with a built-in seeding, germination facility, lighting system and floating hydroponics technology that could produce continual fresh lettuce with minimal technical maintenance and intervention; the aim being to supply these, for example,

[2] This cucurbit pathogen is currently not known to occur in the UK (See HDC Project PC 232. Cucumber, sweet and chilli pepper, and tomato: an assessment of previous and current problems and future risks of *Fusarium* diseases in hydroponic crops, and priorities for research)

in areas of troop deployment in remote areas where access to fresh vegetables was limited.

Lior Hessel gave us details of a turn-key installation they are currently building by the Black Sea in Russia. The structure was predominantly polycarbonate and aimed at lettuce production in an area of some 4,000m^2. We discussed the cost of the Organitech system for the first time and Lior Hessel provided an approximate price of £20/sq ft (£180K/1000m^2) for a turn-key project. This price includes full technical support and a 1 year warranty.

Following discussion, we agreed that a repeat visit to the floating hydroponic lettuce crop at Kibbutz Yagur would be useful to look in more detail at certain aspects of the installation plant. At this second visit we had more time to look in detail at bench design, a reverse osmosis installation to minimise problems with a variable water supply and the insect-proof structure itself.

Visit to Palram Industries Ltd. Kibbutz Ramat Yohanan, Ramat Yohanan 30035, Israel. We met with Oz Elnir (Agriculture Division Manager), Shai Michael (Marketing Director) & Avihu Gilad (Projects Referant) and, following a short meeting, we were given a tour of the manufacturing plant. We were advised that Palram Industries Ltd is one of the worlds largest producers of polycarbonate sheeting. From their initial inception on the Kibbutz some 42 years ago they have built the company up to become a listed company on the Tel Aviv stock market with an estimated turnover of between $140-200M, with 20% ownership by Bayer. Of considerable significance is the fact that they have a large production factory for the twin-skinned polycarbonate sheeting in the UK (near Doncaster in South Yorkshire and also have another plant at Newton Ayecliffe, Co. Durham. They have approximately 300 employees in Israel and a further 200+ in the UK. They reported that approximately just over 20% of their sales are in the UK.

We discussed comparative costs between glass & polycarbonate structures and Lior Hessel estimated a figure of £35-40K/1000m^2 for glass based on Dutch prices. Whilst we were not able to get a precise figure for polycarbonate Lior believed the product competed well with glass. Dr McPherson asked about relative light transmission as this was more important under UK conditions than in Israel. Palram were aware of the need for equivalent light transmission and provided substantial literature to highlight the advances that had been made over the last few years with polycarbonates (This literature is available on request either from Dr McPherson or Mr Smith). There were obvious advantages in terms of thermal insulation, reduced weight (including reduced structural support for the roof), strength, sheet size (and it's impact on light transmission) and health & safety issues.

Dr McPherson asked whether they had any interest in technologies to reduce algal development/build-up on the structure and Palram reported that it was an area that they were interested in though didn't currently have a solution. Dr McPherson is currently looking at potential work in this area using a series of novel copper, zinc & silver ionomers with a private company and there may be opportunities of mutual interest in this respect..

It also became clear quite quickly that Palram were not aware of STC Ltd and the facilities available within 30 miles of their own factory in the UK and Dr McPherson provided company leaflets and offered them the opportunity to visit STC to discuss areas of potential mutual benefit for the UK industry. This is currently being followed up and STC/industry personnel have visited the UK Palram plant in Doncaster and

Tomer Shulman of Palram UK has toured the STC facilities. It is hoped that this development will lead to further opportunities for UK horticulture in the near future.

Location for the Pilot Facility

It is considered necessary that the chosen facility needs to:-

- Be modern and completely separate from other glasshouse units
- Be of a suitable size for adaption to a deep water hydroponic system
- Be appropriate for the installation or use of a discrete environmental control system
- Have smaller, but adjacent, facilities for installation of ancillary equipment
- Have a suitable energy supply for supplementary lighting
- Be readily accessible to LTG members and other visitors as required
- Be suitable for hosting grower open days, seminars and *ad hoc* visits on request.

The ideal glasshouse unit is located at Stockbridge Technology Centre Ltd, Cawood, Selby, North Yorkshire. Importantly, the STC is located fairly centrally in the UK and is close to the major motorway networks linking North-South (A1/M1) and East-West (M62), major trunk roads and railway networks in York and Leeds. Leeds/Bradford, Humberside and Doncaster Robin Hood international airports are all less than 1 hours drive away. For those of a more adventurous nature a small airstrip is available for light aircraft at Sherburn-in-Elmet and, if required, helicopter landings can be made at STC Ltd by prior arrangement.

STC Ltd is based on the former Stockbridge House site which has been an important development facility for UK horticulture for over 50 years. During a period of government restructuring of the UK horticultural R&D base in 2000-2001, the facility secured considerable industry support to remain as a viable unit and was launched as an independent R&D facility for UK horticulture in April 2001. Throughout its 50 year history the STC has had a close association with the UK protected crops, including lettuce, industry and it is hoped that this will continue for a long into the future. One of STC's primary functions is to act as a catalyst is to create a vision for the future of different sectors of the industry and to encourage and generate partnership R&D projects to drive forward technological developments in the industry. In order to achieve this the STC is supported by a board directors with wide industry expertise and this is backed-up by a customer liaison group, selected from both the production and supply sectors of the industry. It should be noted that the STC is the adopted home of the Lettuce Technology Group and regular technical meetings are held on site.

By selecting this site for the pilot study the LTG will be able to draw on the expertise of a multi-disciplinary team with an excellent reputation for timely delivery of high quality research, development and technology transfer programmes. Apart from the glasshouse facility itself the STC can also boast a wide selection of highly secure modern meeting/seminar/conference rooms, laboratories, culture rooms, a commercial 'Plant Clinic' facility, all with excellent parking facilities.

The unit selected for the 'pilot' study (Coded M19) is a Wilco High Light Double Venlo glasshouse. Specifications for the unit are as follows:-

- 896m^2 floor area (909m^2 over dwarf walls)
- 25.6m wide by 35m long
- 4 double Venlo bays with 6.4m trellis orientated East-West

- Central 3m wide concrete road running North-South
- Wide 3.0m doorway access
- Usable growing area ca. 850m^2
- The height to the gutter is 4.0m and to the top of the ridge is 4.7m providing an ideal aerial environment to assist in minimising leaf disease, subject to prevailing weather conditions.
- Narrow profile box section aluminium gutters
- Roof glazing in 1.0m wide glass
- Twin rubber glass seals
- 64 half-pane ventilators, fitted for independent control on both sides of the ridge in staggered formation giving 23.4% ventilation over the crop area. All ventilators are fitted with rubber seals, though are not currently insect-proof.
- Adjacent calorifier house suitable for installation of ancillary equipment e.g. reverse osmosis filtration plant, feed rigs etc as required for the project.

The standard Organitech platform is 2.2m wide and therefore it will only be possible to fit two platforms/bay in the glasshouse identified for the work. Whilst not a problem, it will leave an un-cropped area of approx. 1.5m, assuming a 0.5m pathway between the platforms for access & servicing. It will therefore be necessary to take account of this during evaluation of the technology, relative to soil-grown crops, and make adjustments to the production figures as appropriate.

Summary of the Technologies Required

Self-levelling benches for deep trough floating hydroponic platforms

Polystyrene raft system for plants

Computerised control system for glasshouse environment, floating benches & general crop management

Dedicated propagation unit – with high level of hygiene

Reverse osmosis unit – single system for entire hydroponic system

Supplementary lighting – single intensity throughout the unit[3]

Insect screens for vents

Double door system with positive ventilation - to restrict pest entry

Potential Contributors

Organitech Ltd, Haifa, Israel
Lior Hessel, MD of Organitech has agreed to supply and fit equipment and technology for the floating hydroponics system in a 1000m^2 glasshouse unit at STC Ltd with support from STC personnel. This equipment would be available for R&D purposes for a minimum period of 3 years

[3] Following industry discussion supplementary lighting will not be used at the outset of the demonstration project though, subject to further analysis, could be included as an option in the later stages of the project.

Horticultural Development Council
It is proposed that a project proposal is prepared for HDC to support the costs associated with evaluating the technology for the UK industry over a 3 year period

Stockbridge Technology Centre Ltd
STC Ltd would make an existing 1,000m^2 glasshouse available for the installation and trialling over a 3 year period and would also supply glasshouse and scientific personnel to undertake the evaluation/demonstration, subject to suitable R&D funding.

Regional Development Agency (Yorkshire Forward)
Preliminary discussions with the RDA suggest that funds may be available through the DEFRA Vocational Training Scheme to offer consultancy/training in the novel floating hydroponics technology.

DEFRA
It is anticipated that the lettuce produced within the floating hydroponic system will be established as a speciality high value 'branded' product, marketed through one of the major retailers. It is hoped that a marketing grant will be available to help establish this speciality brand.

Substrate manufacturer
We will need to undertake a comparative evaluation of lettuce propagation in peat blocks with a module system either in rockwool or similar inert medium such as perlite. It is hoped one or more substrate manufactures would participate in the project, subject to appropriate acknowledgement/publicity through provision of the necessary module trays and growing medium free of charge.

Energy supply for Supplementary Lighting
In the event that the industry opt to evaluate the potential benefits of supplementary lighting in the later stages of the project FEC Ltd would be approached, as a partner of choice, for further discussion. It would be necessary to undertake a small ancillary evaluation of the cost-benefit of such supplementary lighting under UK conditions.

Seed supply
Initially we would look to evaluate a high-value lettuce cultivar and Rijk-Zwaan UK Ltd have agreed to supply seed and technology to support the production of the award-winning multi-leaf lettuce cultivar 'Salanova'. In the longer-term it would be necessary to also evaluate other lettuce types and cultivars including 'Little Gem' in addition to various herbs and other potential crops. It is anticipated therefore that a number of the seed companies would co-operate in this high profile project and supply seed and technological support as required subject to appropriate acknowledgement and publicity.

Specialist Lettuce Consultancy
Mr G Smith, Mapleton growers has a wealth of experience on hydroponic lettuce production both in the UK and overseas and it is hoped that his experience will assist the project greatly. At a local level, it will be necessary to compare the floating hydroponics cropping system with conventional lettuce production and it is anticipated that STC Ltd will be able to call on the services of Mr John Sykes, a lettuce grower and former Chairman of Snaith Salads Ltd.

Supply and Installation of Equipment

The floating hydroponics facility will be installed by Organitech Ltd, Haifa, Israel with support from STC personnel as appropriate. The estimated 'ball-park' cost of the equipment and its installation is in the region of £50,000 and this cost will be covered by Organitech Ltd. Lighting will not be installed from the outset though may be considered as an optional extension to the project depending on the initial findings of the work.

Installation Schedule
Subject to project approval an installation schedule would be agreed with Organitech Ltd, hopefully aiming for a first planting in late Autumn 2006.

Project Steering Group
It is proposed that a project steering group will be formed to run the project comprising representatives of the funding bodies, R&D organisations and various industry representatives. It is anticipated that there would be a requirement for no more than 2 formal meetings/year and much of the day-to-day decision-making would be done via an email network.

Scientific Records
A proposed scientific programme will be outlined in a separate project proposal to HDC and will be discussed in detail with project consortium members. It will involve monitoring many aspects of crop production, compiling and analysing the data, and drawing comparisons with conventional soil-grown production systems. The analysed data will be made available to individual growers for comparison with their own production records though the full programme details are beyond the scope of this initial feasibility report. It is anticipated that the site will be accessible to individual growers via a secure webcam facility.

Total Costs over 3 Year period
There is a significant cost for establishing the facility as the existing 1,000m^2 glasshouse will require modifying to re-locate the path & doorways, screen the vents & create a double door entry system to minimise pest entry. In addition to this the floating hydroponic platforms will need to be installed and plumbed in together with all the ancillary equipment. Organitech have agreed to provide and install the floating hydroponic platforms and this provides a significant opportunity. It is possible that we will be able to secure support from other manufacturers and this could also reduce the cost burden to the industry.

Importantly, the technology, if successful would be of applicable to other crops, especially herbs, salad onions & ornamentals and therefore the project should be regarded as cross-commodity. Subject to agreement with HDC it is possible that a range of such crops, but especially herbs & other salad crops would be trialled once the facility is established.

The estimated costs for the project over a 3 year period have been estimated as follows:-

YEAR 1

Input costs	Total (£)	In-Kind Contribution (£)	Net Cost to Project (£)
Establishment costs	70,625	50,000	20,625
12 month net growing season	31,725	3,845	27,880
12 month science input	27,090	2,280	24,810
Project steering group costs	5,325	2,225	3,100

Training personnel & growers	7,325	-	7,325
Marketing development grant	20,000	-	20,000
Reporting/promotional costs	1,950	-	1,950
TOTAL	164,040	58,350	105,690

Establishment costs
Outstanding establishment costs not currently funded = £20,625
Running costs
Supplier/partner contributions = £58,350
Cash contribution sought from RDA = £7,325
Cash contribution for market development = £20,000
Estimated produce income = £10,000
Total non-HDC money = £95,675

Contribution for running costs from HDC in Year 1 = £47,740
Contribution for 33% of establishment costs in Year 1 = £6,875
TOTAL= £54,615

YEAR 2

Input costs	Total (£)	In-Kind Contribution (£)	Net Cost to Project (£)
12 month net growing season	33,905	3,980	29,925
12 month science input	29,005	2,360	26,645
Project steering group costs	5,510	2,340	3,170
Training personnel & growers	12,650	-	12,650
Marketing development grant	5,000	-	5,000
Reporting/promotional costs	2,250	-	2,250
TOTAL	88,320	8,680	79,640

Supplier/partner contributions = £8,680
Cash contribution sought from RDA = £12,650
Cash contribution for marketing = £5,000
Estimated produce income = £10,500
Total non-HDC money = £36,830

Contribution sought from HDC in Year 2 = £51,490
Contribution for 33% of establishment costs in Year 2 = £6,875
TOTAL= £58,365

YEAR 3

Input costs	Total (£)	In-Kind Contribution (£)	Net Cost to Project (£)
12 month net growing season	35,130	4,120	31,010
12 month science input	31,950	2,445	29,505
Project steering group costs	5,705	2,455	3,250
Training personnel & growers	14,440	-	14,440
Reporting/promotional costs	3,755	-	3,755
TOTAL	90,980	9,020	81,960

Supplier/partner contributions = £9,020
Cash contribution sought from RDA = £14,440
Estimated produce income = £10,950
Total non-HDC money = £34,410

Contribution sought from HDC in Year 3 = £56,570
Contribution for 33% of establishment costs in Year 3 = £6,875
TOTAL= £63,445

Summary Costs

Input costs	Total (£)	In-Kind Contribution (£)	Produce Income (£)	Training grant (£)	Marketing Grant (£)	Net Cost to HDC (£)
TOTAL [Over 3 years]	343,340	76,050	31,450	34,415	25,000	176,425*

* Whilst there is an initial higher set-up cost in year 1 of the project the outstanding establishment costs have been divided equally over the 3 years of the project to give an **average annual cost to HDC of £58,808**.

Additional benefits from this Study

Whilst the initial focus of the work will primarily be on protected lettuce other high value salad crops such as herbs e.g. chives will also be evaluated as the project progresses. It is also anticipated that once the facility is established it will provide a valuable resource to investigate other aspects of production to assist in providing an effective 'due diligence' defence to customers.

Additional funding will be sought via the DEFRA Vocational Training Scheme to undertake training of relevant personnel and interested growers in the technology relative to conventional soil-grown production systems.

A further marketing grant will be sought to establish the lettuce produced via the floating hydroponic technology as novel with a price premium due to its freedom from pesticide residues, nitrates and microbial contamination. A figure of £25,000 has been estimated in this respect.

Conclusions

An initial desk study, but including a brief 'study tour' to Israel to evaluate the floating hydroponics technology first-hand, has successfully concluded that it would be appropriate to establish a 'state-of-the-art' hi-tech hydroponic production facility using a novel floating crop production system for the UK glasshouse salad, and other, crops industry.

It is evident from the literature that scientific information on deep water 'floating hydroponic' systems is very limited and that most of the available information relates to hydroponic substrate systems (open or closed) or conventional NFT techniques following the original development by Cooper *et al* in the 1970's. What published information that is available relating to this novel technology is predominantly commercial, linked to companies web-sites aimed at marketing the technology to the industry. One exception to this is work conducted by Cornell University's Controlled Environment Agriculture (CEA) Program with financial support from NASA. Encouragingly, there is considerable interest in developing similar technology in the UK and indeed a few companies have started to make significant commercial investments in this area. As such commercial information from such developments will not be readily available it is appropriate, with HDC funding, to develop an experimental 'demonstration' facility to enable information on the technology to be readily available to growers should they wish to adopt the technology in some form or another.

The initial feasibility study therefore supports the establishment of a floating hydroponic demonstration system to evaluate the latest technology available to growers by growing year-round lettuce, herbs and other relevant crops over a 3-year period as efficiently as possible, thereby maximising labour and other inputs into the crop. It will provide an opportunity to compare any inherent advantages or disadvantages of such a hi-tech system relative to conventional soil production systems. It will also permit a detailed economic evaluation to be undertaken during this 'pilot' study period.

A suitable modern 1000m^2 glasshouse has been identified at STC Ltd and both the glasshouse and the site fully meet the criteria needed for such a project. Organitech Ltd, Haifa, Israel have agreed to be a partner in the project and will contribute financially by providing both equipment and expertise. This will enable the glasshouse to be fitted with a series of floating hydroponic platforms, polystyrene growing units, reverse osmosis unit, nutrient supply and other relevant 'know-how'. Provision has been made for the technical and logistical management of equipment installation.

It has been estimated that the total set-up costs for the project will be £70,625 of which £50,000 will be contributed by Organitech Ltd through provision and installation of essential equipment. This leaves a balance of £20,625 which will need to be funded from HDC at the current time. The intention would be to divide this over the 3 year period of the project.

The annual running costs have been calculated and adjusted to allow for produce income (based on a unit price of 10p/head) and estimated contributions from partners in the project. The budgets include the cost of propagation, and any modifications thereof, planting, trial design, crop management, scientific and commercial assessment and harvesting/marketing. On this basis, the net running costs for the project in year 1 will be £93,415. Of this, £8,350 will be contributed by commercial/industrial partners, £20,000 through a marketing grant and £7, 325

through the DEFRA Vocational Training Scheme and an estimated produce income of £10,000 leaving a balance of £47,740 to be funded from additional sources. In Year two this figure would be £51,490 and in Year 3 £56,570.

It is envisaged that the project will be overseen by a Project Steering Group comprising members of the Lettuce Technology Group and commercial/industrial partners and will be managed on a day to day basis by an experienced Project Administrator at STC Ltd.

Funding for the main project to conduct a scientific evaluation of the floating hydroponics technology over a 3-year period will be sought from the Horticultural Development Council (HDC) as this is a near-market development or demonstration project. It is anticipated that there may be a need for additional scientific study once the facility is established and, where appropriate, separate project proposals will be formulated and submitted to relevant funding bodies/agencies.

Additional funding will be sought via the DEFRA Vocational Training Scheme to undertake a training of relevant personnel and interested growers in the technology relative to conventional soil-grown production systems. It is estimated that a training budget of £34,415 would be required over the 3 year project term for this aspect.

A further marketing grant will be sought to establish the salad crops produced via the floating hydroponic technology as novel with a price premium due to their freedom from pesticide residues, nitrates and microbial contamination. A figure of £25,000 has been estimated in this respect.

This feasibility study has demonstrated that the project can be achieved with annual cash contributions from the HDC, DEFRA and the RDA of approximately £58,000[4], £8,000 and £11,000 respectively in each of years 1, 2 and 3.

Technology Transfer

Events

- Protected Lettuce Seminar March 2006

HDC News Articles

- Feature Article May 2006

[4] This figure includes a component for initial establishment costs (approx. £6,500) spread over each of the 3 years of the project.

References

Albright, L.D. 1996. Controlled environment lettuce-production modules. Proceedings of the 26th National Agricultural Plastics Congress and the American Greenhouse Growers Association Conference, June 14-18, Atlantic City, NJ. pp. 265-270.

Albright, L.D. 1996. The importance of design and control of light in high-productivity controlled environment agriculture (CEA). Keynote paper, presented at the International Conference on Agricultural and Biological Environment (ICABE), August 15-19, Beijing, China. China Agricultural University Press, Beijing, China. 6 pp.

Albright, L.D. and H.I. Henderson. 1995. Efficient cooling and dehumidification technologies for the Cornell University Controlled Environment Agriculture (CEA) Complex. Final Report submitted to NYSERDA. 27 pp. with Appendices.

Anderson, P G (2004) Production and yield of selected edible greens in hydroponic ponds (float beds) in a greenhouse. Floriculture Research Report 16-04. Agricultural Experiment Station, University of Kentucky. 4pp.

Anderson, R G (2005?) Yield of Brassica 'Mei Qing Choi' and 'Tatsoi' in Hydroponic Greenhouse Production. New Crop Opportunities Center, University of Kentucky College of Agriculture. http://www.uky.edu/Ag/NewCrops/brassicamq_tw.htm

Anon (2006) Floating Hydroponics Greenhouse. A hydroponic lettuce demonstration greenhouse operation.. Ithaca, NY 14850, USA. [http://Aesop.rutgers.edu/~horteng/floating_hydroponics.htm]

Anon (1989) Futuristic \vegetable Production – Now!. Publicity leaflet for Swedeponic and Agritech Innovation AB. Sweden. 8pp.

Anon (2005) Publicity Brochure and DVD for a novel fully automated floating hydroponic platform. Organitech Ltd, Haifa, Israel

Battke, F; P Schramel & D Ernst (2003). A novel method for the in vitro culture of plants : cultivation of barley in a floating hydroponic system. Plant Molecular Biology reporter, 21, 405-409.

Both, A.J., L.D. Albright, R.W. Langhans. 1999. Design of a demonstration greenhouse operation for commercial hydroponic lettuce production. ASAE paper No. 994123. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA. 12 pp.

Both, A.J., L.D. Albright, S.S. Scholl, and R.W. Langhans. 1999. Maintaining constant root environments in floating hydroponics to study root-shoot relationships. Acta Horticulturae 507: 215-221.

Both, A.J., S.S. Scholl, L.D. Albright, and R.W. Langhans. 1998. Comparing continuous lettuce production in nutrient film technique and floating hydroponics. Proceedings of the 15th Inter-national Lettuce Conference and Leafy Vegetable Crops Workshop. September 23-26, 1998. Atlantic City, NJ. pp. 16-17.

Both, A.J., L.D. Albright, and R.W. Langhans. 1998. Co-ordinated management of daily PAR integral and carbon dioxide for hydroponic lettuce production. Acta Horticulturae 456:45-51.

Both, A.J., L.D. Albright, R.W. Langhans, R.A. Reiser, and B.G. Vinzant. 1997. Hydroponic lettuce production influenced by integrated supplemental light levels in a controlled environment agriculture facility: experimental results. Acta Horticulturae 418:45-51.

Carruthers, S (1997) Booyong Hydroponics Farm : Bacteria in Hydroponic Culture. Practical Hydroponics & Greenhouses. November/December 1997. 55-63.

Cooper, A H (1988) The ABC of NFT. Grower Books, London.

Cooper, A J (1975). Crop production in a re-circulating nutrient solution. Scientia Horticulturae 3, 251-258.

Danish, W.E. 1994. A growers' guide to lettuce crop production using nutrient film technique in controlled environment agriculture facilities. MPS Project Report. Cornell University Libraries, Ithaca, NY 14853. 68 pp.

Douglas, J S (1976) Advanced Guide to Hydroponics. Pelham Books, London.

Flores, H (1992) Plant roots as chemical factories. Chemistry and Industry. May 1992. 372-377.

Fransen, J T W (1980) Commercial NFT-lettuce growing in Holland. ISHS Symposium on Research on Recirculating Water Culture. Ed. R G Hurd; P Adams; D M Massey & D Price. ISSN No. 0567-7572. Acta Hort. 98.

Goto, E; A J Both; L D Albright; R W Langhans & A R Reed (1996). Effect of dissolved oxygen concentration on lettuce growth in floating hydroponics. Acta Hort. 440, 205-210.

Goto, E., L.D. Albright, R.W. Langhans, and A.R. Leed. 1994. Plant spacing management in hydroponic lettuce production. ASAE paper No. 944574. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA. 13 pp.

Hong, C X & G W Moorman (2005) Plant pathogens in irrigation water: challenges and opportunities. Critical Reviews in Plant Sciences 24, 189-208.

Ikeda, H (1984) Recent developments of hydroponics in Japan. In : Proc. 6th Int Congress on Soilless Culture, Lunteren, pp.661-672.

Jackson, M B (1980) Aeration in the nutrient film technique of glasshouse crop production and the importance of oxygen, ethylene and carbon dioxide. Acta Hort. 98, 61-77.

Kao, Te-Chen (1987). Evaluation of the DRF hydroponic vegetable culture system. In: The First Proceedings of a Symposium on Horticultural Production under structures. Taichung, ROC on Taiwan. (In Chinese).

Kao, Te.Chen (1991) The dynamic root floating hydroponic technique : year-round production of vegetables in roc on Taiwan. Taichung District Agricultural Improvement Station, Hsiang, Changhua, ROC on Taiwan. 10pp. [http://www.fftc.agnet.org/library/article/eb330.html]

Kuo, Fu-Yao & S W Wu (1989) Continuous cropping problems and management of disease and pest on the vegetable facility culture. In : The Second Proceedings of a Symposium on Horticultural Production under Structures. Taichung, ROC on Taiwan. Pp. 172-191. (In Chinese).

Mathieu, J.J., L.D. Albright, K. Kurata, and E. Goto. 1998. Whole crop simulation model of nutrient uptake within a recirculating hydroponic system: a literature review. Proceedings of the 1998 Joint Meeting of The Society of Agricultural Meteorology of Japan, The Japanese Society of Environmental Control in Biology, and The Society of Agricultural Structures, Japan. pp. 210-211.

Spensley, K ; G W Winsor & A J Cooper (1978) Nutrient film technique-crop culture in flowing nutrient solution. Outlook on Agriculture, 9, 299-305.

Schwarz, D & W Gross (2004). Algae affecting growth in hydroponic systems. J. of Hort. Science & Technology 79(4), 554-559.

Thompson, H C; R W Langhans; A J Both & L D Albright (1998). Shoot and root temperature effects on lettuce growth in a floating hydroponic system. J. Amer. Soc. Hort. Sci. 123(3), 361-364.

de Villiers, D.S., R.W. Langhans, A.J. Both, L.D. Albright, and S.S. Scholl. 1999. Intermittent CO_2 enrichment for hydroponic lettuce production. Abstract. HortScience 1:532.

Wheeler, E.F., L.D. Albright, R.M. Spanswick, L.P. Walker, and R.W. Langhans. 1998. Nitrate uptake kinetics in lettuce as influenced by light and nitrate nutrition. Transactions of the ASAE 41(3):859-867.

Wheeler, E.F., L.D. Albright, L.P. Walker, R.M. Spanswick, and R.W. Langhans. 1994. Plant growth and nitrogen uptake Part 2: Effects of light level and nitrate nutrition. ASAE paper No. 947505. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA. 14 pp.

Acknowledgements

We would like to thank Mr Lior Hessel and his scientific and administrative colleagues at Organitech Ltd, Haifa and also the various growers, research organisations and companies we visited during our brief visit to Israel. We would especially like to thank Ashley Levinsohn, UK representative for Organitech Ltd who kindly acted as our guide during the visit. We were especially grateful for his excellent driving as this made the visits much more timely and efficient and also prevented us from getting lost, hijacked and/or shot.

Finally, special thanks to HDC, members of the Lettuce Technology Group and the UK industry more generally who kindly provided funding for this exploratory trip.

Appendices

Appendix 1: Photographs of the floating hydroponics technology as installed at Kibbutz Yagur, Haifa, Israel.

Plate 1: General view of the plastic structure housing the floating hydroponics system, at Kibbutz Yagur.

Plate 2: General view inside the structure at Kibbutz Yagur showing the floating polystyrene trays with Kos lettuce

Plate 3: Close-up of the young perlite raised plug plants from propagation

Plate 4: General view of the young plants n the polystyrene rafts post-planting.

Plate 5: General view along the house, noting the evaporative cooling and shading above to assist workers during harvesting and other in-crop operations.

Plate 6: View of lettuce root development in the hydroponic system. Note the total absence of any discoloration.

Plate 7: Close-up of the Organitech platforms and the depth of water. Note the considerable algal growth on the surface and around the water-line of the polystyrene rafts

Plate 8: Close-up of the automated push rod mechanism for moving the polystyrene rafts around the platforms

Plate 9: View of the reverse osmosis units used to remove all contaminants, including base nutrients and pathogens, from the water supply.

Plate 10: Photograph of chives growing using the same floating hydroponics technology

Plate 11: Harvested produce being packed ready for dispatch