Controlled Environment Management And Plant Physiology in a Closed Production System

A report for

By: Anthony J Brandsema

2005 Nuffield Scholar

Completed November 2007

Nuffield Australia Project No (ANF-7A)

Sponsored by:

© 2008 Nuffield Australia.
All rights reserved.

This publication has been prepared in good faith on the basis of information available at the date of publication without any independent verification. Nuffield Australia does not guarantee or warrant the accuracy, reliability, completeness of currency of the information in this publication nor its usefulness in achieving any purpose.

Readers are responsible for assessing the relevance and accuracy of the content of this publication. Nuffield Australia will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying on the information in this publication.

Products may be identified by proprietary or trade names to help readers identify particular types of products but this is not, and is not intended to be, an endorsement or recommendation of any product or manufacturer referred to. Other products may perform as well or better than those specifically referred to.

This publication is copyright. However, Nuffield Australia encourages wide dissemination of its research, providing the organisation is clearly acknowledged. For any enquiries concerning reproduction or acknowledgement contact the Publications Manager on ph: 02 6964 6600.

Scholar Contact Details

(Name)	Anthony Brandsema
(Address)	8 Brandsema St. Turners Beach Tasmania 7315
Phone:	03 6428 2319
Fax:	03 6428 2694
Email:	jbrandse@bigpond.net.au

In submitting this report, the Scholar has agreed to Nuffield Australia publishing this material in its edited form.

Nuffield Australia Contact Details

Nuffield Australia
Telephone: (02) 6964 6600
Facsimile: (02) 6964 1605
Email: enquiries@nuffield.com.au
PO Box 1385, Griffith NSW 2680

Acknowledgments

I would like to thank:

- Nuffield Australia for the opportunity presented to me. I feel privileged to belong to an association of forward and positive thinking individuals not only here in Australia but throughout the Nuffield network worldwide.

- Rural Industries Research and Development for their support. The involvement of such sponsors ensures the viability of the scholarships into the future.

- The other travellers on the Global Focus Program. They helped by asking questions and posing theory from a myriad of different origins. The companionship was rewarding and the friendship will be eternal.

- Jacqueline and Paul van Dokkom of Leusden, The Netherlands. They were great support in a foreign language land.

- Herman and Saaj, Theo and Arun van de Kaaij, Berlikum, The Netherlands. For opening their door, letting me ask so many questions, feeding me and treating me as family.

- Rob Alleblas of Wilke van de Sande, Naaldwijk, The Netherlands. For the great friendship and hospitality while in Mexico together.

- Gerrard van de Wilke of Wilke van de Sande, Naaldwijk, The Netherlands. For taking the time to show me why it is so important to get it right.

- All at the PTC+ training school, Ede, The Netherlands. The hospitality and flexibility shown towards me for my time there demonstrates a truly international facility. Also the other international students for the cultural experience.

- Ineke Oosterhof, Kudlestaat, The Netherlands. It was good to be driven around by a local in a congested place.

- Tim Pratt N.Sch., Kenilworth, The United Kingdom. Great hospitality and great exposure in a topic relevant to mine.

- John Yeomans N.Sch. Newtown, Wales, The United Kingdom. A chance to do the laundry and get some mud on the boots.

- Terry and Liz den Dulk, Beresford, The United Kingdom. A home away from home.

- Graeme Smith, President of the Australian Hydroponic and Greenhouse Association, Woodend, Victoria. Tour guide in Canada, industry stalwart.

- Mark and Chris Millis, Sue Korevar and Hoerst Sjostedt. Australian greenhouse tomato growing colleagues. For the education and the chance to experience Canada together.

- All of the growers, who opened their greenhouses, who were so free with their information and so willing to share their experiences.

- All of the representatives of supply companies of the industry in all of the countries visited. They invested time with me, for which I'm grateful.

- Marcus and Elly, John and Anna Brandsema for the support at work in my presence and absence. It proves how much can be done without me.

- My wife, Jillian. Jillian has continued to encourage me with my Nuffield experience and managed our family of three boys with resolve and courage.

Contents

Executive Summary

Greenhouse vegetable production is placed on a pedestal for achieving high production from a relatively small area with outstanding efficiency in water use. Greenhouse production is also labour intensive and a high consumer of energy. Greenhousing creates opportunities for supplying produce over an extended season with consistent quality and supply. To compete in the world market growers are trying to reduce their cost of labour with technology and using energy more efficiently.

1. The environment of a greenhouse presents the grower with many issues. These issues range from dealing with the management of their plants, technology and staff to provide the plants with the best possible chance of maximum production.
2. Australian greenhouse growers have often been left to their own devices in their search for growing methods, which will enable them to produce to the world's best standard. Often the fast growing environment of the greenhouse traps the grower into a culture of catching up with the plant's development, and provides little respite for the grower to manage the environment of the greenhouse or the plants at an objective level.

New tools available to the greenhouse grower include:

- Carbon dioxide enrichment
- Recycling of nutrient run off
- Alternate sources of energy
- Labour saving devices/methods

Growers looking to enter the greenhouse industry or expanding their current operations need to carefully consider the following implications:

- The demand for the product they are to produce
- The ability and knowledge of the grower
- Suitability of the greenhouse location in relation to the access to markets, raw materials, including the supply of energy, labour and climate
- The investment

Labour for the manual work to be performed within the greenhouse was certainly in short supply as witnessed in Australia, The Netherlands, The United Kingdom and Canada. Mexico was the only country visited where the labour supply was not an issue, to the extreme where labour replaced forklifts in packing sheds.

There is a good market for the produce from greenhouses. There is a trend to identify the grower on packaging materials, particularly in The United Kingdom. There the supermarkets were trying to show the consumer that the grower could be located just outside the village, and not half way across the other side of the world, where growing standards could be poor or excessive carbon dioxide was emitted transporting the produce to the market.

The topic chosen, “Controlled environment management & plant physiology in a closed production system” provided me with ample scope for investigating the greenhouse industry internationally. Learning by seeing it for myself, or even better, working in the greenhouse alongside the grower, presented an opportunity of learning that the unique Nuffield experience extended to me. The Nuffield experience has also drawn me to places I would not have considered travelling to. The scholarship introduced me to a world of issues and challenges, which will relate to our own family based greenhouse operations in time.

Study Goals

The greenhouse industry is a highly technologically driven industry. Trying to keep abreast of the changes can be difficult while being consumed in the day-to-day activities of an operation. Securing the right information can be a major component of any study. Has the information been proven in practice? This should be studied in places apart from the source of the original information or in this instance apart from the source of the technological advance.

There are many aspects of greenhouses, all of which require an advanced understanding to help make the greenhouse a complete integrated system. Knowledge and understanding for me is best gained by "seeing and doing". The Nuffield Scholarship allowed a flexible opportunity for me to study in a manner consistent with my needs.

I studied "Controlled Environment Management and Plant Physiology in a Closed Loop System", to essentially equip me with the necessary tools to help grow our own business. The consequence of this is the recognition by the Australian industry of my position to implement new knowledge and skills and therefore to be an example of the direction in which the industry is heading.

I intentionally visited and studied in the following countries for the following reasons:

- The Netherlands: This country is consistently referred to as a centre for greenhousing. I secured a stay with a greenhouse grower for two weeks. I worked in his 7 hectare greenhouse, gaining lodgings as well as the opportunity to ask questions from a range of topics including plant culture, computer operations and market and labour issues.

  I attended a greenhouse specialist training facility, PTC+. "Learning by doing", is their motto. All theory was practised in the greenhouse next door.

  I met many greenhouse supply representatives who afforded me time by visiting with their clients. One such operation visited was a greenhouse operation which included the production of 18 hectares of cherry tomatoes. This particular operation was notoriously difficult to visit.

- Belgium: I investigated the manufacture and design of biomass boilers, with particular emphasis on a boiler applicable for a smaller greenhouse operation such as ours. The cost of energy has risen globally for many industries including greenhousing. Biomass energy is one source considered as an alternative.

- The United Kingdom: I visited Tim Pratt N.Sch. Tim works as a consultant specialising in energy supply and use. He has seen a doubling in energy costs in the greenhouse industry since 2004. We visited several operations and looked in the supermarkets at the current trends for tomatoes. I visited John Yeomans N.Sch. and discussed the pitfalls of leasing land to wind generation.

- Canada: There is a vibrant greenhouse industry in British Colombia and Ontario. The Canadians use European technology and have learnt to adapt it to their growing operations. Biomass boilers being were used extensively as a means of cost reduction. The value of the Canadian dollar continues to increase against the U.S. dollar, with the U.S. being huge and the majority of their market. I was presented with a fantastic opportunity to join members of The Australian Hydroponic and Greenhouse Association tour of Canada to look at production systems and to attend the Canadian Greenhouse Conference in Toronto, Ontario. This tour group was organised and lead by the association's president, Graeme Smith. Several of the Australians were leading greenhouse producers. Being with this group presented opportunities to discuss issues from home as well as the merit of new ideas seen on the tour. I also spent a short period with Eric Ritchie N.Sch. who was also looking at biomass utilisation.

- Mexico: I visited Mexico as it is considered as the fastest developing greenhouse industry in the world. I met with a Dutch greenhouse heating company representative and travelled extensively throughout Mexico meeting with his contacts. It would have been difficult to visit some of the operations without this necessary contact. It was interesting to note that many growers were considering geo-thermal energy. Labour costs are low in Mexico resulting in dedicated communities living in close proximity and supporting the often very large greenhouse operation.

- The United States: San Francisco, California. I looked at several 'farmer's markets' to gain an understanding of the concept in a large population area. I discovered many 'heirloom' type tomato varieties and discussed pros and cons with producers.

Background information

Greenhouse vegetable production in Australia has been largely established by migrants since post World War 2. The first wave of migrants from Europe settled in places like Murray Bridge in South Australia and Launceston in Tasmania. Many came from rural areas and had experienced or at least seen greenhouses. For example, in European countries many people grew vegetables and even table grapes in greenhouses of various shapes and sizes. They created structures to supplement their meagre winter vegetable diet. These Europeans, like those to follow, did not have English as their first language and therefore it was difficult for them to assimilate. Migrants instinctively felt they could grow things easily. They used the methods from home including the greenhouse structures.

More recently we have seen a wave of Lebanese migrants settle the western suburbs of Sydney and the Vietnamese move into run down Italian structures on the Virginian plains close to Adelaide in South Australia. Most of these structures were very low tech, consisting of nothing more than a glass or plastic covering on a timber frame. Few had heating or control of the crop, which meant that the market was often over supplied. All growers shared the same peaks and troughs of production. People of the subsequent generation moved away.

"There are also generational implications for the industry with Australian born generation X and Y workers shying away from the repetitive and labour intensive work to the 'softer' industries of IT, finance, management, marketing and human resources." (Australian Vegetable Protected Cropping Industry Strategic Plan 2006 – 2020).

My grandfather, Wilco, and my father, John's story is aligned to the migrant scenario. The young migrant family moved to Australia to escape the bad memories of occupation and the threat of communism. Finally settling in Turners Beach on the North West Coast of Tasmania, the men cleared coastal land and started to grow poultry and vegetables. In the early nineteen sixties my grandfather tried to grow tomatoes in gravel culture, early hydroponics, but failed. He did not have access to the water testing facilities and the soluble fertilisers that he was reading about in the latest growing journals from The Netherlands. The family resigned to growing vegetables and tomatoes in the soil, for the fresh market. My father recognised a gap in supply of the tomato market during a period after Christmas in Tasmania when the other 'local' growers in old glasshouse structures had cleaned out their crops and were having a Christmas break.

He built a very basic plastic covered, timber framed greenhouse to provide basic cover from the temperate spring and summer of Tasmania. Timing was the key. He started picking tomatoes straight after Christmas for a period of about ten weeks. Sometimes the summer in Tasmania is wet, and the crop, because of the lack in heating and control, suffered decimating losses due to the fungal disease, *botrytis*. Sometimes there was a good dry summer, which equated to outside producers and home gardeners also having a good season, therefore creating an over supply of produce in the local market. It was difficult to achieve the right balance, but the system proved profitable by consistently producing during that window for several years.

While producing in this basic structure, John also produced cucumbers in a plastic covered, air heated structure he had designed himself from what he thought were the many good ideas of other growers, both here and overseas. Profitably operating for several years, he sought to semi-retire and sell the business as a going concern, but had trouble finding a buyer who could believe the production achieved in such a small growing area, or someone willing to work to the same extent as John would.

What to do? John successfully managed to entice his two sons, Marcus and Anthony to leave their current employment as tradesmen, and convincing them of the opportunities of greenhousing. The timing of the 'boys coming home' coincided with the price increase of the soil fumigant, methyl bromide. This pointed at the need to change the growing system in the greenhouse from soil to hydroponics, as soil could not be easily replaced in the greenhouse structure.

Equipped with trade knowledge and the experience of a greenhouse grower of many years, the team set out to rationalise the business into only growing tomatoes and building a high tech greenhouse with information gleaned from overseas. A greenhouse was secured from France, a control computer from New Zealand and a heating system from The Netherlands. The greenhouse was built and technical skills were put to the test of growing in the new environment. Mistakes were made. The appetite for knowledge became insatiable.

This story may be indicative of many greenhouse operations in Australia. There are a number of themes to be highlighted to give the reader a greater awareness of the greenhouse industry:

- Europe is seen as a centre for greenhousing, however, technology must be adapted to each different growing climate of Australia. Temperature, relative humidity and light are all different in Europe. The search for knowledge is usually done in Europe as they have championed greenhousing, as their population requires intense production facilities in less than optimal conditions.
- Migrants have traditionally moved the industry forward, though it should not be taken for granted that the next generation wishes to remain in the industry. This can lead to reluctance to invest. Investors these days are largely corporate.
- The industry is dominated by the volatility of the fresh market. The fresh market is greatly influenced by 'the type of year we are having'. It can be said that the fresh market relies on an unseasonal disaster somewhere else in the country.
- There is a good market for consistently produced greenhouse vegetables. The greenhouse provides a climate where the season of production can be extended. The sheltered environment is capable of producing blemish free produce, which may command a premium.
- Heating and control of the greenhouse have become major factors for greenhouse production.

"There are now more than 1600 hectares of greenhouses in Australia for vegetable, herb and flower production". (Australian Vegetable Protected Cropping Industry Strategic Plan 2006-2020) "Farm-gate value of $600 million p.a., equivalent to 20% of total value of vegetable and flower production." (Australian Vegetable Protected Cropping Industry Strategic Plan 2006-2020).

Discussion

My topic has two components, namely "Controlled Environment Management" and "Plant Physiology in a Closed Loop System". I wanted to explore the management of the greenhouse in relation to the tools and equipment installed within the greenhouse and wished to separate these from the responses of the plant and look at the growing of the plant as an independent topic. Of course the plant responses are dominated by the result of the greenhouse environment and a link will be made as relative humidity and control is discussed.

Controlled Environment Management

The greenhouses visited as part of my scholarship tour can all be categorised as incorporating a high degree of technology and automation. There are many hectares of "low tech" greenhouses being used in Australia. However with the climate of Tasmania, our operation's location, the push into high tech, high input greenhousing is prevalent. Automation equipment and computers manage new greenhouses. Utilising the automation equipment and computers is a skill to be developed by the grower in each instance. The grower needs to become acquainted with some basic environmental manipulations to enable management for the crop grown to be the most productive. There can be different periods of the 24 hour day requiring different parameters to be set. These periods will need to be introduced and adjusted in duration according to the stage of the particular crop, the day light length or even the type of growing media incorporated to name a few factors.

A good example is the utilization of time periods. It is important to start heating the greenhouse before dawn to prevent a sudden increase in greenhouse temperature once the sun begins to heat the greenhouse. The mass of the fruit will not allow the fruit to gain temperature at the same rate as the atmosphere leading to condensation. This condensation can lead to unsightly russeting or fine cracks on the surface of the tomato. A general rule is that the greenhouse temperature should not rise more that 1 Deg. C. per hour in that morning period. Conversely, at dusk the temperature in the greenhouse should be dropped suddenly. The effect is that the assimilate will travel to the warmest parts of the plant. If the fruit is the warmest part of the plant, the assimilate will increase the size of the fruit-a generative effect.

To continue with another separate example, a young, immature crop will need less irrigation than a mature crop being harvested. The timing of the first irrigation of the day is dependant on the occurrence of dawn; the size of the initial irrigation of the day depends on the media selected to avoid "flushing"; the time of reaching the media full point is to be regulated; and the final irrigations of the day determined by the amount of draw down required by dusk.

Experience with these types of principles is to be guided through introducing professional training either on farm or in the environment of a classroom. The courses offered at PTC+ in Ede, The Netherlands, introduce managers to these principles and relate them into practice in the adjoining greenhouses.

Automation equipment and computers

Automation equipment refers to the machinery used to operate various components of the greenhouse structure. Computers are the tools used to operate the automation equipment. The computer makes adjustments and triggers the equipment in response to user defined parameters as well as parameters that the grower has no control over, such as light.

There are many greenhouse computers available on the market, all of which have their benefits and their shortcomings. Selection criteria is based on past experience, recommendation and user friendliness towards that type of grower. There are two major suppliers, Priva and Hoogendorn. Each system is extendable according to the size and diversity of the operation. The computers are designed as an off-the-shelf item, which often means that the grower must know which parts are relevant for them. Each system also runs a Windows based software package designed to help the grower watch for trends as well as providing the grower with a simple method of changing set points. Each computer supply company provides 24 hours a day, 7 days a week technical support as well as training courses designed to help the grower optimise the use of the computer.

The 'garbage in, garbage out', phrase is as relevant for greenhouse computers as for the home/business based P.C. The grower must know what he wants in order to define the parameters he assigns in the computer. The quality of the information going in has a bearing on the quality of the information presented or process being conducted. For example, if the external light meter has suddenly failed due to a tree branch striking it, the computer will make responses applicable to little or no light conditions.

Heating

There is a range in the heat requirements of greenhouses throughout Australia. Most greenhouse vegetable crops including tomatoes, capsicums and cucumbers require heating, as the value of basic vegetable crops and their climatic requirements, make the proposition unviable. The tomato, capsicum and cucumber crops have originated from sub-tropical to tropical climates, indicating their intolerance to cooler temperatures. Usually a minimum greenhouse temperature of 15 Deg. C. is acceptable for tomatoes. Heating is also used as a tool for the control of relative humidity, particularly applicable for tomatoes where fungal diseases flourish in relative humidity levels above 80% during day light hours and 85% in the night. Lower relative humidity levels also increase the plant's transpiration rate, therefore the rate of assimilate transfer, resulting in increased production.

It seems that there is also a range of the different types of heating fuel used. Although expensive, natural gas and L.P.G. is the energy source of choice, as this form of energy has the bi-product of carbon dioxide. While carbon dioxide in many people's minds has a negative impact, particularly in relation to climate change, it is also an essential compound in photosynthesis. Carbon dioxide is injected into the greenhouse to maintain ambient levels of 350ppm. If the vents of the greenhouse are closed and the plants are photosynthesising, the greenhouse environment can even be deficient of carbon dioxide levels necessary for efficient growth. Photosynthesis can also be promoted and enhanced when greater than ambient levels are achieved. The practice of enriching the environment above ambient levels is becoming more popular in Australia. Carbon dioxide uptake of a crop can be a maximum of 70kg / hectare / hour (van Onna).

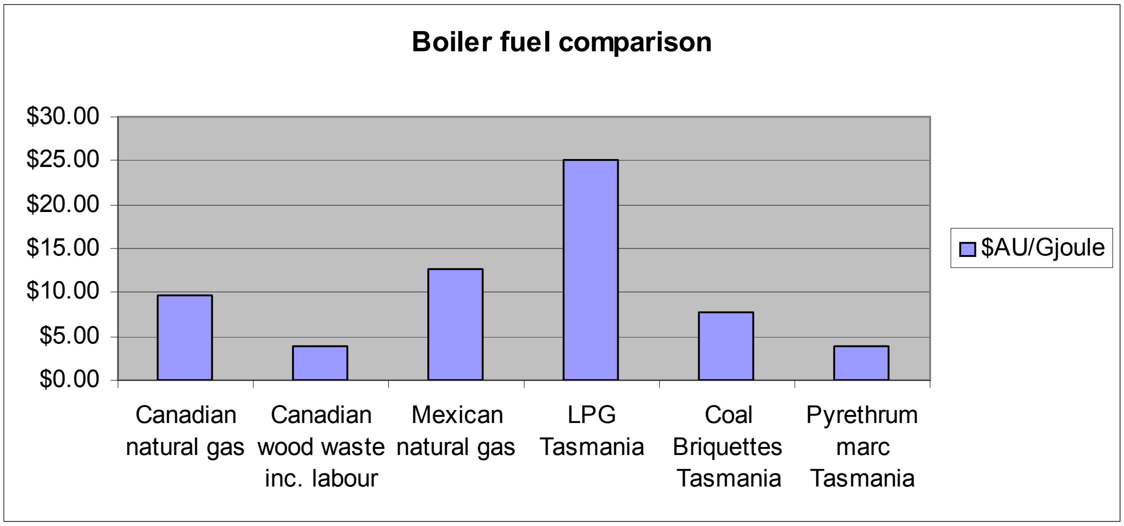
Other sources of energy used in Australia are brown coal, brown coal briquettes, black coal, waste oil and electricity. There is some movement toward biomass burning, with one grower reputedly burning peach pips from a nearby cannery in Shepparton.

The Dutch growing system has traditionally developed around the supply of natural gas. Many operations using natural gas inject the emissions of carbon dioxide into their greenhouse. The carbon dioxide is produced by the boiler for enriching the greenhouse during the day. The heat is also produced during the day. The heat must be stored in water in a buffer or holding tank for use during the night, or other cool times of the day.

Picture 1. Carbon dioxide extraction fan. Mexico.

Picture 2. Large, vertical heat storage or buffer tank. The Netherlands.

Graph 1. Below is a graph showing the relative cost of energy from various sources:



This graph highlights the competitive advantage of the bio-mass derived fuels as opposed to using natural gas or L.P.G. It should be noted at this point that the solid fuel systems do not provide the advantage of enabling carbon dioxide enrichment. Carbon dioxide needs to be injected into the greenhouse in pure form from commercially available sources in the absence of gas energy. Gas derived carbon dioxide is less contaminated with carbon monoxide and nitrous oxide than the solid fuel sources, which are potentially lethal for labourers and plants in the greenhouse. The handling systems of solid fuels are also more complicated, relying heavily on mechanical means of transferring the fuel by way of augers and conveyor belts, which are prone to blockages and breakdowns.

The Canadians consider bio-mass heat generation as a means of gaining a competitive advantage. The Canadian dollar is increasingly becoming an equivalent to the U.S. dollar, meaning that the Canadians were increasingly searching for methods of cost reduction, as the U.S. is the major customer for the Canadian grown greenhouse produce. The Canadians are prepared to invest in bio-mass boiler technology, with an added advantage of the move away from reliance on fossil fuels, and gaining carbon credits.

Picture 3. Bio-mass storage heap. Municipal waste. Canada.

Picture 4. Part of the handling systems required for using solid fuels. Canada.

The availability of the fuel source is in proportion to the cost of the fuel. For example, a highly processed fuel source like L.P.G. or electricity, while being readily available to most commercial operations, is usually more expensive than an unrefined fuel. These types of unrefined fuels include coal and biomass and need to be sourced locally to provide the crucial cost advantage in an environment where every cost saving creates or even enhances viability. If a fuel is to be transported large distances from it's source, the cost advantage of the fuel may be depleted or lost. Greenfield selection would also consider the fuel source readily available.

The introduction of the Tickleman System from The Netherlands has increased the productivity in greenhouses. The Tickleman System refers to the engineering of the heating distribution pipes used in the greenhouses to ensure even heat throughout the entire production area. Irregularities in the system where hot water is used in pipes can translate to cold spots in the greenhouse and less productivity. "Where there is a hot spot in the greenhouse, there must also be a cold spot", (Alleblas).

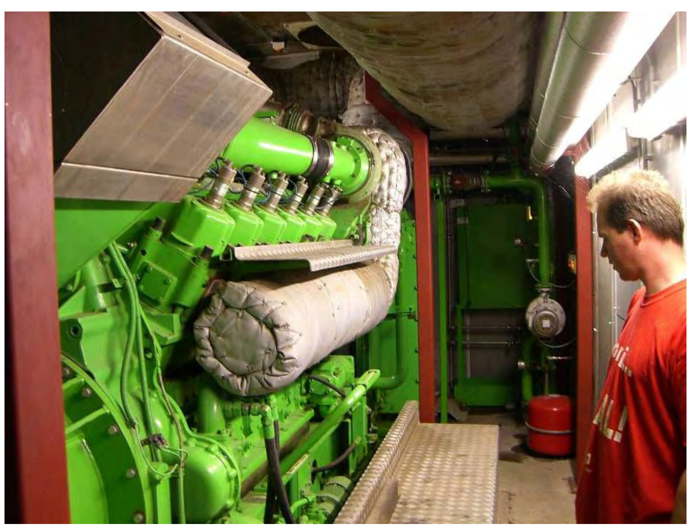
Innovations are aimed squarely at cost reduction through efficiency increases or the utilisation of conditions unique to a location. Some innovations discovered from the scholarship travel include:

- The "Closed Greenhouse". There is a considerable research effort being spent on a closed greenhouse concept. If the greenhouse is kept closed there is the potential for an excessive heat build up during the summer months. The heat is captured in water and stored in an aquifer below the greenhouse and re-released back into the greenhouse during the winter months. This concept is particularly popular in The Netherlands, where the aquifer is large and never far from the surface. The spin off of having the vents kept closed is the 30% reduction in heating required from an external energy source, exclusion of insect pests is achievable and carbon dioxide is not lost through ventilating. Disadvantages include the initial cost of pumping and heat pump infrastructure, build up of relative humidity and site location dependant on an available aquifer. www.**themato**.nl
- Thermal screens. These screens are suspended in the roof of the greenhouse and are drawn closed at night to retain the heat in the greenhouse. Selection of the type of screen is dependent on the characteristics desired. For example a grower may require an open weave where relative humidity build up under the screen could be a problem. Usually the screening material is based on aluminium type foils that reflect heat. The saving in energy of a thermal screen is estimated at 5-10%. (Ag Energy Co-operative). The installation of screening materials vertically on side and end walls of the greenhouse, provides a 0.5-4% energy saving. (Ag Energy Co-operative). Some screens are also designed to shade the crop during the day in extreme high light/temperature conditions.

- Geo-thermal. This is particularly prevalent in regions of high seismic activity, for example, Mexico. Growers are drilling wells on their properties to access water with elevated temperatures. This water is circulated through a heat pump arrangement to increase the temperature further before going to the greenhouse for heating. Additional to the heat gained, in every case where warm/hot water is tapped, carbon dioxide is also present, enabling free enrichment for the grower. In one instance on the visit in Mexico, the grower had access to a geothermal well and this was his only source of water for the operation, meaning he was looking at even destroying the heat so that he could use the water to feed the plants without scalding the roots.

- Co-generation. This is used in operations using L.P.G. or natural gas and is particularly popular in The Netherlands and the United Kingdom. A gas generator is installed at the grower's cost to supply electricity back into the national grid. The by-products of the gas fired generator are heat and carbon dioxide. The heat and carbon dioxide are used for the production of the greenhouse crop. It was reported to me by a Dutch grower that his selling power back to the national grid was more profitable than the tomato crop grown. For Australia this concept is uncommon as power is usually sourced from centralised generation plants. This idea helps to keep infrastructure costs of electricity companies down but also supplies electricity close to the customers. The grower in the photo below quoted 2 million Euros for installation.

Picture 5. Co-generation unit. Generator. The Netherlands.



Cooling

Growers will select either active or passive methods of cooling their greenhouse, according to the site location and budget. Active refers to a method where the environment is actively cooled by using electrically operated mechanical equipment such as fans or heat pumps. These systems are expensive to install. Passive refers to using methods which require less electrical components and equipment, such as vents that gently let the warm air flow from the greenhouse or shade screen which restricts the ultra violet component of light from heating the greenhouse.

The general rule is that it will cost more to cool a greenhouse than it will to heat a greenhouse. For a new operation, site selection with consideration of this rule is critical. If the site is to be in a region of high day (35 Deg. C+), and night temperatures, often experienced in the majority of Australia in summer, cooling the greenhouse will be particularly relevant for greenhouse tomatoes. One grower visited in Mexico was considering using a pad and fan method of cooling to extend his growing season as it was too hot for part of the year in his region for viable greenhouse production. An active method of cooling would need to be incorporated to achieve the desired effect. At an open wall of the greenhouse a pad of a permeable cardboard type material is placed at one end of a greenhouse. Water is run down the pad. At a distance of no more than 20m a fan is placed. This fan pulls air from out side the greenhouse through the pad and water and effectively cools the environment by evaporative cooling. If the grower decides to locate the fan too far from the pad, the cooling effect is lost as the plants are actually heating the air as it passes toward the fan. This can lead to inefficiencies in path length such as too much path in relation to growing area.

For cooler climates the use of vents on the greenhouses may be adequate. The most commonly used vents are in the roof for maximum use of the 'chimney effect' and are supplied according to the grower's selection from a range of configurations usually offered. Plastic greenhouses can have a continuous length vent on either or both sides of the roof ridge, while glasshouses have short panels consisting of 2 to 3 panes of glass, again on either side of the ridge. The vents are usually on both sides of the roof ridge to give flexibility when venting on the leeward side depending on wind direction. Growers may choose to use insect screening over the vent to exclude insects from the greenhouse. This will have the undesirable effect of reducing the ventilating ability.

Picture 6.   Continuous vent in plastic greenhouse.   Note insect screen. Mexico.

Picture 7. Glasshouse venting panel. Note stirring fan. The Netherlands.

Humidity Control

The control of the humidity within the greenhouse has given the grower an elevated ability to determine the viability of the crop through both production and disease control. The plants in a relatively closed environment of a greenhouse will contribute to the environment's relative humidity as their transpiration adds water to the air. Control of the relative humidity is usually performed by the computer according to parameters determined by the grower in relation to particular desired effects for different stages of growth and for different times of the day. For tomato crops, it is desirable to have a relative humidity below 85% during the night time period and below 80% during the day. Control is usually achieved by a combination of vent adjustment and heating pipe temperature adjustment. Achieving the desired humidity levels may be difficult and expensive particularly in high humidity climate and weather conditions. The installation of circulation fans in the modern greenhouses is now common as a tool to distribute the relative humidity evenly throughout the greenhouse.

The relative humidity of the greenhouse environment directly influences the transpiration rate of the plants in the greenhouse. If the moisture in the air is high, there is little or no movement of water from the plant into the air, resulting in low transpiration rate. Improved transpiration helps the making of assimilates, the transport of nutrients and sugars through the plant and the cooling of the plant. Study at the PTC+ Learning Centre of relative humidity was intense and highly technical. The relationship between air temperature and the amount of moisture in the air possible at that temperature was explained by use of the Mollier Diagram. Dew point was also explained. "If the temperature of any subject in the greenhouse is more than +/- 4Deg. C. colder than the air temperature, condensation will occur. Based on the temperature of 15-20Deg. C. and relative humidity of +/- 80% ." (van Onna).

Plant Physiology in a Closed Loop System

The reference of "Closed Loop System" can be described in two ways. The greenhouse is a relatively closed growing environment, in comparison to growing out in the field. To take the closed greenhouse concept to the extreme, as stated previously in the innovations covered in this report, a new concept of keeping vents completely closed is being explored. The other meaning of "closed" can be assigned to the concept of keeping the nutrient run off of the production system within the system. This can raise the spectre of nutrient and pathogen build up in the system, each requiring a management system.

Irrigation

Water availability / quality

The availability of water is a paramount consideration when selecting a site for a greenhouse venture. The quality of the water is to be considered equally, however treatment of the water is possible to improve quality at an expense. Canadians used locally reticulated water drawn mainly from snow melt while Mexico was the only place visited where the availability of water for the growers in each instance was a major concern. It seemed that site selection was ill informed in some cases, with the growers relying on ground water, presenting as geo-thermal. One site visited had 6 wells and was drilling their 7th. The level of salts may compromise ground water quality.

The Dutch experience showed a heavy reliance on rain water whilst many also draw from nearby canals. The canals are subject to temperature rises in summer, with the risk of algal growth, and possibly leached nutrients and other contaminants. My host site relied on the supply of water from a treatment plant that included reverse osmosis. Reverse osmosis can supply water with potentially all salinity removed. The treatment plant is capable of 150m3/hr. The grower joined a cluster of 10 greenhouse growers in the area to build the facility to overcome the prohibitive cost of such an installation. My host nominated 9m3/hr consumption, but is now looking to build a storage pond, as this nomination would not cater for an expansion in their operations. All roof collected water is diverted to a storage pond, usually lined to prevent seepage and cross contamination from ground water from the usually below sea level site. A rule of thumb suggested was consumption of 2 litres / m2 / hour in the greenhouse, remembering that up to 40% of the water will be recycled back into the system.

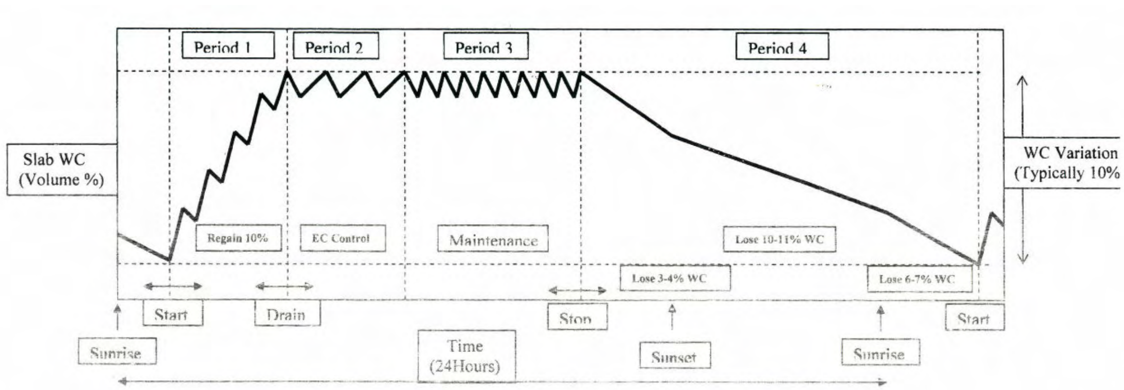
Picture 8. Cluster of greenhouse growers, including van de Kaaij, my host, drawing from one treatment plant. The Netherlands.

Timing

Across all sites visited in all locations, particular to hydroponic media based systems, there was a basic principle of irrigation adopted. To adopt this basic principle, greenhouse computers were always utilised. Volumes are determined by the grower in relation to the stage of growth and for the time of the year. The graph below diagrammatically demonstrates the principle of:

1. Starting the first irrigation a determined time after dawn.
2. Slowly wetting up the media to assist lateral spreading of nutrient solution through the slab, for a period of approximately two hours.
3. Achieving run off after two hours after first irrigation.
4. Controlling the electro-conductivity (E.C.) in the slab.
5. Maintaining nutrient solution levels for the rest of the day.
6. Last irrigation at a determined time before dusk.

Graph 2. Steering Water-Content in media (tomatoes).



(Graeme Smith Consulting)

Recycling Nutrient Solutions

The build up of nutrients within the closed hydroponic system is possible, as the plants may only take up only a limited amount of any one nutrient. Usually a nutrient feed is supplied to the plants in excess, so as not to create a deficiency of that nutrient in the plant. This scenario may lead to the problem where undesirable nutrients, for example, sodium and chloride, being less required by the plant for development, can build up the system. This can lead to a toxic build up and replace the valuable nutrient component of the nutrient supply. An undesirable method of reducing the build up is to renew the nutrient solution by "dumping", or desirably, by recycling the nutrient through a reverse osmosis filtration unit, which is designed to remove particular elements from water based solutions.

The testing of the run off water from the plants for nutrients is an essential part of the duties to be performed when closing the hydroponic system. For most Australian growers the nutrient solutions are sent for analysis to a laboratory, the results of which are then sent to a third party consultant who interprets the analysis and determines an adaption to correct the trend of nutrients within the solution in relation to a set of targets. In The Netherlands, the grower sends solutions away for analysis to a laboratory who then responds to the grower by supplying adaptions determined by comparison to blue print levels for different stages of growth and for different times of the year. This practice was not limited to The Netherlands. Growers in Canada and Mexico also sent their water samples to The Netherlands.

The build up of pathogens in the system is another concern for the grower. These pathogens could include *Phytopthera spp.* and bacterial diseases. There are a number of ways in which the nutrient solution may be cleaned or sterilised for re-entry into the hydroponic system. Ultra violet (U.V.) light sterilisation units were by far the most popular method of sterilising the nutrient solutions witnessed. Other methods include pasteurisation, ozone treatment and sanitising chemical injection.

Picture 9. U.V. light sterilising unit. The Netherlands.

Picture 10. Pasteurising Unit. The Netherlands.

Set points

There are many references in this report alluding to the grower needing to constantly changing set points. The grower has many tools available to him to monitor trends such as the grower's environment control computer, plant monitors and irrigation/run off monitors. There are also a number of measurements the grower can physically perform and record to verify trends and to view the crop personally. Below is a table of characteristics the grower can look for to help determine whether the crop of tomatoes is generative or vegetative.

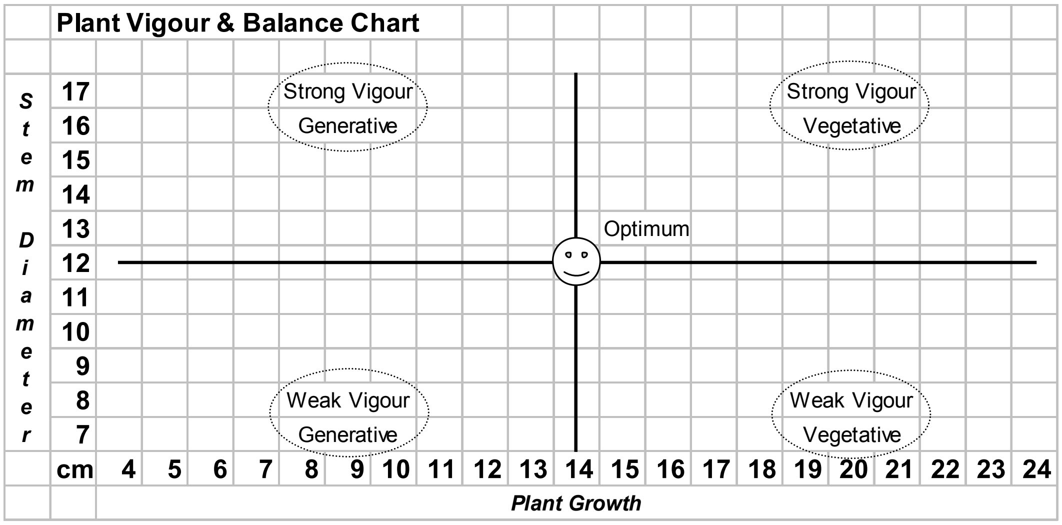
Table 1. Aid to crop judgement during high fruit load phase.

Characteristic	(too) Generative	(too) Vegetative
Flowering	close to the top, opens fast. Uniform and rapid flowering within the truss	far under top, opens poorly sepals "stick" together, poor uniformness of flowering within truss
Flower colour	dark yellow	pale, light in colour
Leaf	curled in top, short, dark and firm, few "growth spots"	flat in top, open, long, light and soft
Truss Stem	thick, sturdy, short and curved	thin, long and sticking upwards
Fruits	big, many, good shape, quick development	small, few, poor shape, slow development

(De Ruiter Seeds)

The grower can physically measure the plant and can use a table as below to objectively determine whether the crop is generative or vegetative.

Table 2.



(Graeme Smith Consulting)

Recording this type of information is only beneficial if the grower acts upon the trends he is observing. Making the right moves according to the information is the key to being able to translate records into action. The table below enables the grower to steer the plant:

Table 3. Actions which will enable steering of the plant.

Steer	**Generative**	**Vegatative**	**Margins**
difference day:night temp.	bigger	smaller	0 - 5 Deg. C.
cooling day to night	quickly (evening cooling)	slowly/not	0 - 4 Deg. C. / hour
pipe temp	raise	lower	0 - 80 Deg. C.
growth pipe	3 trusses under flowering truss	at level of truss to be harvested / off	0 - 60 Deg. C.
humidity deficit	raise	lower	2 - 8 g/m2
ventilate (outside temp. >10 Deg. C.)	more	less	
CO2	more	less	350 - 1000ppm
E.C. mat	higher	lower	3 - 6 mS/cm
E.C. drip	higher	lower	2.5 - 4 mS/cm
water content mat	lower	higher	50 - 80%
cycle length and frequency	longer and less	shorter and more	75 - 100mls
start drip	later	start drip earlier	0 - 3 hours
stop drip	earlier	later	0 - 5 hours
truss pruning	less	more	
truss supporting	more	less	

(De Ruiter Seeds)

Seed companies often publish these types of charts with their notes for particular varieties depending on the type of variety that it may be. A variety may by nature be particularly vegetative, therefore the need of the grower is to push the growth towards being generative and to refer to the above chart for tools on how this can be done. The following example is also lifted from the De Ruiter Seed Truss Tomato Quality Guide.

"Evening cooling has vegetative as well as generative elements. If the air temperature is lowered quickly, the fruit temperature will lag behind. The plant temperature decreases more quickly than the fruit temperature and assimilates are attracted more to the fruits (generative effect). At the same time, the mat temperature also lags behind the air temperature (even more than does the fruit temperature), and the root pressure (turgor pressure in the plant), increases (vegetative effect). By making an evening cool short and deep, the generative effect is bigger than the vegetative. Increasing transpiration brings down the turgor pressure and is a generative action". (De Ruiter Seeds)

Labour

"Protected cropping directly employs 7-8 people per hectare – over 10,000 people nationally. The indirect employment multiplier for fresh produce is estimated to be two, suggesting that the industry creates over 20,000 jobs." (Australian Vegetable Protected Cropping Industry Strategic Plan 2006 – 2020)

In The Netherlands, The United Kingdom and Canada, as with Australia there is a shortage in the supply of labour to perform the sometimes menial tasks within the greenhouse operations.

The cost of labour and the low return on produce in these countries force the managers to adopt many labour cost cutting measures. Such measures included:

- Automated picking trolleys, designed to move automatically as a picker moved their leg across an electronic eye, therefore keeping hands free to pick. These trolleys would also return to the packing shed independent of human help.

Picture 11. Trolleys returning full to the packing shed automatically. The Netherlands.

- Packing shed automation of un-stacking picking trolleys through to automated pallet stacking and wrapping. The use of automated punnet filling machines for cherry tomatoes is also common.

Picture 12. Electronic eye on picking trolley. The Netherlands.

- Labour tracking devices, used to determine the time spent for each operation by each particular employee. Various systems were witnessed, usually associated with the greenhouse control computer. This would help the manager assign labour to the most suited employee for the task to be performed.

Picture 13. Worker registration panel.

Note: finger print touch pad on lower right of panel. Canada.

It was particularly interesting for me to witness the use of foreign labour in the greenhouses. In The Netherlands, my host greenhouse, used Polish and Moroccan labour. The laws in The Netherlands were written to prevent this labour staying for longer than 9 months. I came to realise that although the Euro in Europe was the common currency, the value of the Euro is different in each country. For example, a loaf of bread in Poland may be 0.90 Euro cents, whereas in The Netherlands, a loaf of bread may be 2.00 Euro. This indicates that the cost of living is certainly higher in The Netherlands than it is in Poland. The Polish labour would come to The Netherlands and find that the cost of living while they were working would erode their potential to save and be cashed up for the time they returned home. Coincidently, whilst visiting the United States, I watched a documentary on television highlighting the same problem with the Mexican workers coming over the border to the lure of the American dream. Their problem was worse, where the difference in the value in the currency was greater and the exploitation of the workers greater also leading to the demonstrated case that the cost of living for the Mexicans prevented them from sending any money from earnings home, let alone saving enough money for them to return home after a season's work.

Picture 14. Foreign labour accommodation. The Netherlands.

Picture 15. Foreign labour accommodation. Canada

Mexico was a complete contrast where labour seemed to be used in excess to the point where I had the impression that the workers were there being paid to do little, rather than them being a social drain in the community in which they were living. These communities in Mexico are often directly associated to the greenhouse operation, supplying whole families of labour, childcare facilities, sports fields and shops. I witnessed at least two locations in Mexico where the greenhouse was sited in an isolated area. Often the closest town was many kilometres away. It became apparent that a site might have been chosen as an area, which was surplus to the government's needs. It was also discussed that the government encouraged inhabitation of these isolated locations to prevent the rural population from migrating to the cities, therefore placing an extra drain on the already stretched infrastructure within those cities. One site was located in an isolated place because the operator had a good (questionable), relationship with the sole supplier of natural gas in Mexico.

Picture 16. Sports field built for workers. Mexico.

Market

- "Protected cropping is the fastest growing food producing sector in Australia – AHGA reports industry growth, nationally to be up to 6% per annum."
- "Supermarket retailers have identified that their growth comes from customers attracted to innovative products, and so continuously seek consistent lines of high quality, attractive food products to meet this demand. Protective cropping systems provide the ideal environment to assure product security, quality and safety at profitable levels."
- "Major domestic retailers are sending strong market signals they wish to increase to proportion of tomatoes they source from greenhouses from 17% in 2006 to 50% of purchases in five years."

(Australian Vegetable Protected Cropping Industry Strategic Plan 2006 – 2020)

We have seen supermarkets dominate the market domestically resulting in their strategies being at the forefront of the consumers shopping arena. The strategy of generic labelling of packaging has been an uncomfortable strategy from the grower / packers perspective, as they would prefer that the consumer would identify a quality product with that particular grower / packer. Sweeping changes originating from The United Kingdom came through with new ideas of generic labelling. It was interesting to witness the newest trends in The United Kingdom and the way they are now reverting to a more of a personal approach with the labelling.

Picture 17. Pre packed tomatoes. Note: British flag, name of the grower, grower location and variety. The United Kingdom.

Since my trip the trend is reverting further, to arrange logistics so that the supermarket draws from the local growers first, with the grower having the responsibility of delivering to the supermarket directly. This gives the perception that the produce is local and harvested freshly.

The 'farmer's market' in the United States of America, (U.S.A.) is a similar concept of the grower, representing himself in the market located close and giving the perception of freshly harvested. This is taken a step further in the farmers market, as the grower can present produce to the market, which is not normally available to the supermarkets because of the longer supply chain and storage issues. A good example in point is the use of 'heirloom tomato' varieties. These varieties are non hybridised varieties and are based very much around the types of varieties associated with home grown tomatoes and the perception of the flavour achieved in the home grown varieties. These can be presented as such as the supermarket chain would not be appropriate for a variety which, when ripe, will not be firm nor withstand the rigours of the transport chain. The farmers presenting in this market would usually be small family based farms of less than 20 acres and growing a range of seasonal vegetables. Some would extend their tomato season by building a low technology greenhouse. Often these farms would have door sales, which would have a low local customer base. The farmer would often attend the farmers market to initially sell surplus produce and then become reliant on the larger population base and extended customer base.

Picture 18. 'Heirloom tomatoes' as presented in the farmers market. U.S.A.

Another concept discovered on the Global Focus Program component as well as my own individual study tour was the concept of the farmers working together to limit production to create an artificial shortage in supply resulting in a strong demand, therefore a good price for their produce. This was evident in Manitoba, Canada, as we visited a carrot producer who declared that he along with two other carrot growers lobbied the provincial government to create a carrot regulating board. Of course the grower we visited was a member of that board!

In The Netherlands I witnessed a meeting of tomato growers who used the same marketing company. It was discussed at that meeting that the growers would lower their price all together, therefore eliminating the chance that buyers would target individual growers and lever the price before approaching other growers with a new lower price. This would prevent the opportunity of creating a price war which could force growers to sell at below cost. This practice is called collusion and is illegal in Australia.

Conclusions

The topic chosen, “Controlled environment management & plant physiology in a closed production system”, provided me with ample scope for investigating the greenhouse industry internationally. Often, learning by seeing it for oneself, or even better, working in the greenhouse alongside the grower, presents an opportunity of learning that the unique Nuffield experience has extended to me. The Nuffield experience has drawn me to places I would have not considered travelling to. The scholarship introduced me to a world of issues and challenges, which will relate to our own operations in time.

The fresh vegetable market is vibrant and dynamic industry of ever changing trends and seasonal fluctuations. The volatility in the market can be a positive, as those who produce consistently will become relied upon, at times even commanding a price for their product which is not a reflection of the market price, because of their reliability in supply.

Technology is only as valuable as the ability or knowledge of the grower running the greenhouse. Appropriate training for growers will enhance their capabilities, either formal training through institutions or by ‘learning by doing’. A few practical measurements and their interpretation translating to actions is an important part of the basic training of managers.

Staff needs to be considered as an integral part of the operation and rewarded for their efforts. It helps the consistency of the operation to have reliable staff. Staff will become more reliable if the appropriate incentives are there.

Innovation needs testing. Those who test innovation are usually determined enough to create the successful adoption of the innovation into their operations as a permanent fixture. Those who are prepared to look over their fences, and travel in the pursuit of innovation will ultimately be the ones who discover these innovations.

Recommendations

Since returning from my travel, in the quietness of a weekend or a very early morning, I have considered what I have brought back to my individual enterprise, or even to the wider industry. I would like to think that colleagues would consider my Nuffield Scholarship as an extension of my views, creating depth in my character and knowledge.

- The Nuffield Scholarship program is to be commended.
- There needs to be a vegetable grower included with each year of Scholarships.
- There needs to be a strong link forged between Nuffield and the vegetable industry, as the youth in the vegetable industry are seeking direction.

The enterprises visited on my tour were truly inspirational, in their commitment to their practice and the wider industry. There was not one business that I left with a feeling that it was time wasted. Visitors to our businesses, should leave with a positive impression, as was my experience.

- Take time to open your door to visitors. Whether they be school children, service clubs or indeed other growers. They will ask questions, which may be obvious, but now and then, someone will ask you a question which just may cause you to change your thinking.

Technology is available for most facets of the greenhouse operation. Knowledge and training in the technology is paramount for the technology to perform at its optimum. ‘Learning by doing’, certainly was the teaching method, which was appropriate for me. Experiencing the greenhouses in so many places, with so many different variations and combinations of the same theme, was truly the best way for me to learn.

- Growers need to remove themselves from their own operation to gain an ‘experience’ which will help them to concentrate on a new system or technology item.
- Technology is proven somewhere. Find out where and talk to the operators of the technology and not just the agent or seller.

Australian farmers are recognised as being some of the best farmers in the world. They are very receptive to new ideas or innovations, and deal with some of the harshest conditions in the world. This indicates that they are also very aware of the issues being presented in the form of climate change.

Internationally there is a move to growing crops for bio-fuel or indeed using bio-fuel in their on-farm equipment. Greenhouse growers are also aware of the climate change issues, and have adopted technology which makes them very efficient with energy and water.

- Greenhouse growers must look at alternatives to fossil fuel as an energy source if they are to remain in business, as social pressure will start to swing the direction of the shopping dollar to environmentally cleaner produce. Carbon credit trading will be a reality for all soon, presenting an opportunity for the greenhouse grower.
- The use of closed hydroponic systems should be looked at for a myriad of vegetable crops, if we are serious about stretching our water resource to its full potential.
- Consideration in siting of new greenhouses should be done at an industry strategic level. The concept of clusters around shared water treatment facilities, packing shed and boilers should be embraced as a logical way of gaining greater efficiency.

References

Australian Vegetable Protected Cropping Industry Strategic Plan 2006 – 2020
Horticulture Australia 2007
Sydney Australia
www.horticulture.com.au

Energy Savings Technologies for Greenhouses
Ag Energy Co-operative Ltd. 2006
Ontario Canada
www.agenergy.coop

Environmental Control, Practical Management for Horticulturists
Van Onna, Ben
PTC+ Practical Learning Centre Ede
Department of Horticulture 2006
The Netherlands
www.ptcplus.com

Introduction to EC & pH Measurement in Crops
Graeme Smith Consulting 2005
Woodend, Victoria, Australia

Plant Vigour and Balance Chart
Graeme Smith Consulting 2006
Woodend, Victoria, Australia

Steering Possibilities to Generative / Vegetative
De Ruiter Seeds
Rijk Zwaan Australia Pty. Ltd.
Dyelesford, Victoria, Australia