Horticulture Innovation Australia

Final Report

Robotic strawberry harvesting (Part 2)

Rudi Bartels
Magnificent

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BS09014

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Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

HAL Project Number: Project BS09014 (10 March 2011)
Project Leader: Rudi Bartels
Email: rudi@agnificent.com
Tel: 0427 661 633
Fax: 07 3217 8737
Key Personnel: Raymond Daniels & Phillip Palk

Purpose of this report

This report completes the requirements for HAL Project BS09014.

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Date of the report

24 March 2011

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Media summary

The strawberry industry faces serious challenges, including:

1. Labour supply being highly dependent on government visa programs.
2. Rising inputs costs while the price of strawberries has remained stagnant for 15 years.
3. A steady increase in imports.
4. Public perceptions concerning pesticide residues and environmental impacts.

With the support of HAL, AusIndustry, Sunray Strawberries and Griffith University, Magnificent is developing an automated strawberry production system that addresses these threats by:

1. Significantly reducing the labour required, thus:
    a. Freeing growers from dependence on government visa programs, and
    b. Enabling the employment of a small permanent labour force, at wages that are competitive with other sectors of the economy.
2. Reducing the cost of production, making it possible for Australian growers to:
    a. Aggressively compete with imported fruit, while
    b. Opening avenues to growth through exports.
3. Enabling year-round production that can compete with out-of-season imported fruit.
4. The strawberry production system under development addresses public perceptions as:
    a. In the covered production environment, it is a lot easier to control pests and diseases which means that organic production or pesticide free production is easier to implement.
    b. Environmental impacts:
        i. There is no discharge of sediment, agro-chemical and nutrients.
        ii. Capture of carbon dioxide inside greenhouse to increase yields.
        iii. No need for field cultivation and tractor-spraying resulting in reduced energy consumption.
        iv. The primary waste is organic coco-peat which is biodegradable, whereas plasticulture is prohibitively expensive to recycle.

The automated strawberry production system consists of a rotating growing system that utilises covered production and robotics to enable fully automated harvesting and packing. The components for the new strawberry production system have been procured and partly commissioned. To demonstrate the advantages of the new production system it is recommended that the system be brought into production in the 2011 season to test the production system through the growing season.

For further information on the automated strawberry production system please contact Rudi Bartels on 0427 661 633 or email rudi@agnificent.com

Technical summary

Magnificent Pty Ltd is pioneering strawberry production automation that addresses the challenges posed by labour supply, rising input costs, imports and public perceptions that the industry is facing. The project builds on the field harvesting technology developed in project BS08014 to develop a new strawberry production system with high levels of automation.

The new automated production system takes well established technologies such as hydroponics and covered production and merges it with the robotics technology developed in BS08014. Much of the progress during the reporting period was on research into and development of the proof-of-concept for the fully automated production system. The major research findings and industry outcomes included:

1. **Hydroponic strawberry production.**
    - Visited hydroponic growers in Florida and Mexico to review status of hydroponic production at similar low latitude with similar warm growing conditions.
    - Researched hydroponic production technology.
    - Implemented hydroponic system that is similar to leading hydroponic strawberry growers.
2. **Covered strawberry production.**
    - Visited covered producers in Florida and Mexico to review status of covered production at similar low latitude and with similar warm growing conditions.
    - Researched local options for covered production.
    - Procured and built a greenhouse with climate control.
3. **A rotating growing system.**
    - Researched high density strawberry production.
    - Identified suppliers of rotating production systems.
    - Procured a rotating growing system.
    - Installed and commissioned the rotating growing system.
4. **Robotic harvesting**.
    - Researched options for a low cost and high speed robotic actuator.
    - Procured robotic actuator.
    - Developed design concepts for gripper, machine vision and chassis.
5. **Automated grading and packing.**
    - Demonstrated proof of concept for blemish detection.
    - Demonstrated proof of concept for fruit sizing.
    - Demonstrated proof of concept for weight estimation.
    - Developed list of suppliers of packing shed automation equipment.

The work undertaken during this period demonstrated key concepts for the new production system and has set in place the foundations for the next phase of development during which the system will be brought into production. Further work is required to optimise the agronomic aspects (especially cultivar trials) and to fully automate picking and packing. It is strongly recommended that researchers in plant breeding, agronomy and entomology work closely with Magnificent to ensure a multi-disciplinary approach that will ensure the quick resolution of any issues during the coming season.

Other growers are also strongly encouraged to visit the greenhouse. Visits by other growers during the season will be the main means of technology transfer, specifically during the biannual Queensland Strawberry Growers Field Day. At the Field Day growers from across Queensland will be given a detailed insight of the new production system.

Introduction

The return on capital for field strawberry production is reducing while the risk profile has been steadily increasing. Due to the confluence of several factors including:

1. **A static strawberry price** that has remained flat for more than 30 years (see Figure 1).
2. **Increasing input costs,** especially labour, which typically accounts for 55% of the cost of production.

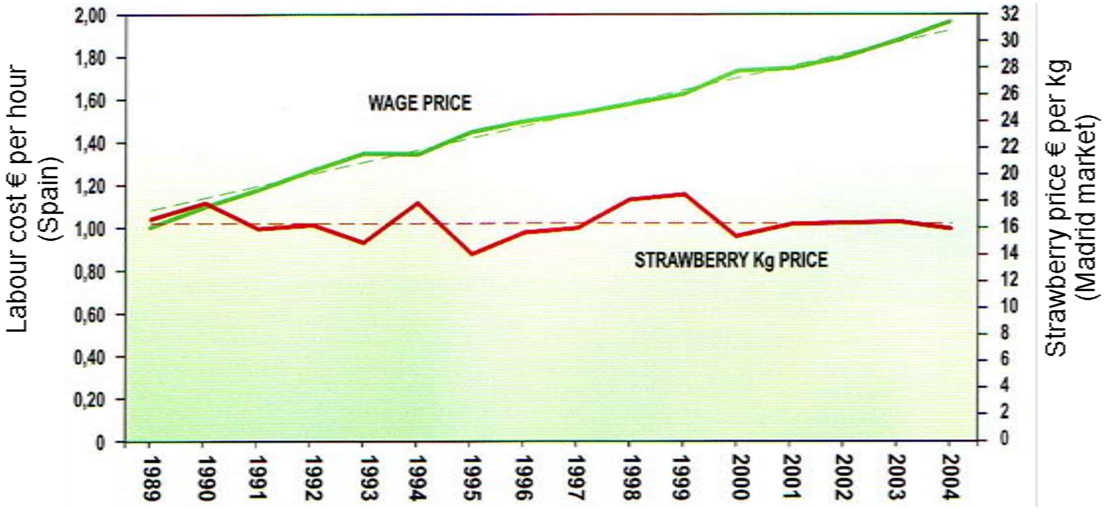

Figure 1: Historical cost of picking strawberries and strawberry price at the Madrid market.

3. **Labour availability**: As living standards continue to climb, the work force is increasingly averse to undertaking labour intensive back-breaking strawberry picking work while exposed to the elements. Growers are increasingly reliant on the vagaries of the Government's migrant labour policy.
4. **Increased compliance costs**. Growers must comply with increasingly stringent standards in order to be able to supply the large retail chains that now account for more than 80% of the market. Examples are the Woolworths Quality Assurance Standard and SQF1000.
5. **Agro-chemicals:** Increasing restrictions on the use of agrochemicals such as methyl bromide has made it difficult for growers to cost effectively control pests and diseases. Growers are obliged to adopt alternatives control measures which tend to be more expensive and less effective.
6. **Extreme weather:** Extreme weather such as hail, frost and heat waves can cause significant damage or even wipe out a crop. As the production costs continue to increase while the returns remain static, the risk-return profile of these extreme weather event is increasing devastating to growers.
7. **Imports:** The Australian industry is increasing threatened by fresh strawberry imports from low labour cost countries. This threat is exacerbated by:

   a) **Improvements in transportation enabling technologies**, such as cultivars with longer shelf lives and better refrigeration technologies that allow fresh strawberries to be shipped more than 11,000 km from California to Australia.

b) **The strengthening dollar** that makes Australia an attractive export market for countries with weaker currencies and/or lower labour costs.

c) **High levels of employment in Australia** that increase the scarcity of labour for harvesting fruit and increases the cost of the available labour relative to growers from exporting countries such as the USA who have easy access to large pools of cheap labour under the H-2A visa program.

d) **Future carbon taxes** which will likely increase production costs for domestic producers while imported fruit will likely not be subject to similar carbon taxes or if subject to these taxes will likely be taxed at a lower rate.

e) **Pests:** Pests from kangaroos through to ducks cause losses from direct yield impacts through to damage to the infrastructure. The traditional means of pest control are increasingly restricted in the eco-sensitive peri-urban communities where the bulk of the crop is grown.

Technology for production automation is at a point where there are no longer significant cost and implementation barriers to cost effective robotic harvesting, grading and packing. This phase of the development expands the concepts for automation that was developed for the field harvester (BS08014), to encompass a more holistic approach. This more holistic approach was developed as a result of a risk analysis that was carried out subsequent to BS08014. The analysis identified technical challenges to field harvesting that would be costly to circumvent, namely:

1. **Foliage movement:** In the field, it is difficult to move foliage that obscures fruit without damaging the fruit that is obscured and also potentially damaging the plant. With fruit hanging form substrate foliage obscuring fruit is much less of a problem.
2. **Grading and Packing:** While automated grading and packing is possible on a field harvester it is difficult to justify the capital cost required given the relatively slow throughput of each field harvester. With covered production the fruit can be quickly conveyed to a central point where one set of packing equipment can be pack the production from multiple harvesters.

The new production system is a system for growing strawberries includes full automation of the labour intensive operations of harvesting, grading and packing. The main components of the new production system are:

1. **Waiting Beds** that are located external to the production area and that are used to grow the strawberry plants from the runner stage to the fruiting stage. At the fruiting stage the plants are transferred to the covered production area.

2. **Rotating Growing System** that rotate substrate grown plants to enable the production of strawberries at high planting densities.

3. **Robotic Harvesters** (including Picking Head) that selectively harvest strawberries and pack them directly into punnets that are conveyed directly to the Packing Shed.
4. **Central Controller,** coordinates the Rotating Growing Systems and Harvesters while providing a control interface as well as remote diagnostics and support capabilities.
5. **3rd Part Supply** consisting of readily available components and services that are supplied to the horticultural industry as illustrated in Figure 2**Error! Reference source not found.**. This 3rd party supply includes packing shed equipment for weight checking, fast chill, packing punnets into trays and stacking trays onto pallets.

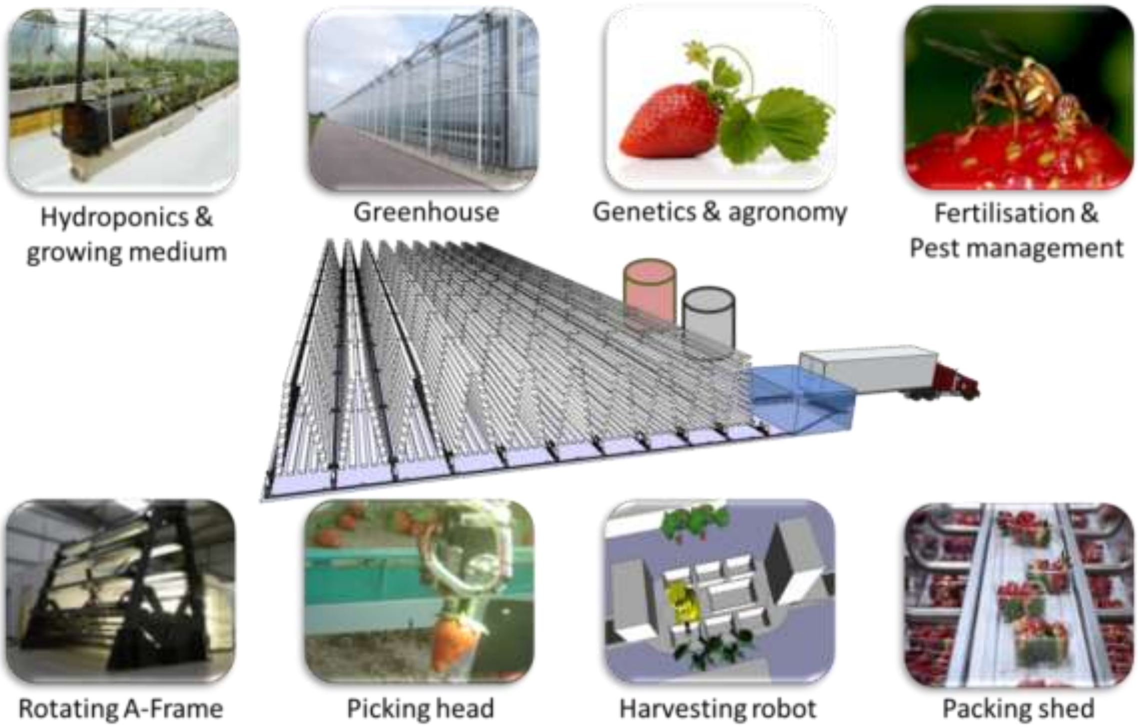

Figure 2: Concept for fully automated strawberry production system illustrating key components.

The Production System enables growers to grow strawberries of a consistent high quality, at low cost while reducing the production risks through:

1. **Better labour availability** as a small core permanent staff is required that is less than 5% of the peak itinerant staff requirement for seasonal field production. This substantially reduces labour supply risks while also reducing production costs.
2. **Covered production** considerably reduces the impacts of adverse weather and associated risks. In addition, covered production increases the market price as more than 90% of fruit grown under cover is supermarket saleable fruit whereas for outdoor production supermarket saleable fruit typically varies between 50 and 80% depending on the weather. Of the saleable fruit only about 5% is graded at second grade in covered production systems whereas for field production between 50 & 80% can be

graded as second grade. Second grade fruit typically sells for half the price of first grade fruit. Further, the Production Systems enables the production of softer highly flavoured varieties that can have an additional price premium as illustrated Figure 3.

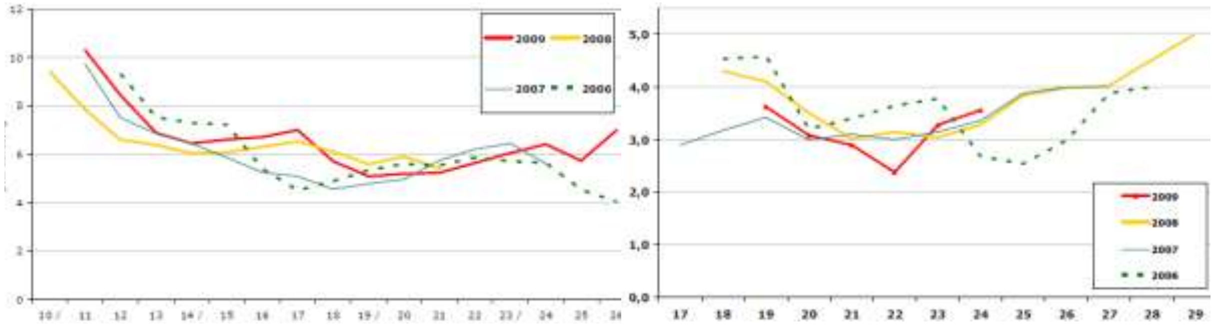

Figure 3: Price in France of flavoured soft cultivar (left) versus imported cultivar (right).

3. **Reduced risk of pathogens** and associated reduced compliance costs, as there is little risk from human borne pathogens and full traceability from plant to the punnet.
4. **Agro-chemical usage** is typically less than 5% of the agro-chemical usage for field production with considerably reduces risks associated with agro-chemical (especially pesticide) contamination. Organic or pesticide free production is also easier to implement, with organic or pesticide free commanding a price premium of up to 100%. This reduction in agro-chemical usage is possible as:
    a. Less fungicide usage as precipitation is excluded in the covered production environment.
    b. Herbicides and soil fumigants are not required as the growing medium is sterile.
    c. The covered production environment provides a controlled environment where biological control measures can be easily implemented as there is very limited ingress of new pests to disturb the balance between pests and predators.
5. **Pest damage** by pests such as ducks and kangaroos can be almost eliminated as production is inside an enclosed structure.

Magnificent continued to research the state of the art for robotic harvesting, robotic grading & packing, hydroponics and covered production as well as research into vertical production systems (see Appendices). Development in this phase was focused on procurement and construction of a greenhouse and rotating growing system as well as the components required for automation of production. The proof-of-concepts for key technologies were also developed.

Materials & methods

Search Vision System: A stereo machine vision system test rig was built. The rig was used to trial fruit detection (blob detection) and positioning using stereo (multi grid techniques) which enables faster picking as the move too point for the robotic actuator can be very quickly determined in three dimensional space without the need to continuously recompute the position as was required with BS08014.

Grading Vision System: Preliminary trials of blemish detection were undertaken. These trials used actual blemished fruit with images captured under controlled lighting using the stereo machine vision test rig.

Weight Estimation: Random samples of fruit from the packing shed were used for this trial. For each fruit, three images of the fruit were captured separated by 120 degrees around the circumference. The peduncle was removed then the fruit was weighed. The volume of each fruit was then determined by submerging the fruit in a measuring cylinder. Several approaches to estimating the volume were then tested using the 3 images for each fruit item as the basis for the estimate.

Rotating Growing System: The rotating growing system is an existing design developed by A&B Hydroponics.

Greenhouse: A suitable greenhouse design was developed to accommodate the rotating growing system in conjunction with VP Structures.

Hydroponic System: The initial concept for the hydroponics was to use Nutrient Film Techniques (NFT). After consultation with leading experts both in Australia and overseas the design for the hydroponics has been changed to a drip irrigation system.

Robotic Actuator: A systematic review of available robotic technologies was undertaken.

Revised Machine Vision: The machine vision components have been redesigned so as to enable stereo vision with a static camera and lighting system. This is possible due to the high positioning accuracy of the Epson C3.

Peduncle Detection: A simulated environment using plastic strawberries was used to improve the peduncle detection algorithm. This was necessary as the hydroponic production system was not yet operational and the topography for the field strawberry is significantly different to that for the hydroponic production.

Results

Search Vision System: The trials that were undertaken proved the concept for the use of stereo vision for fast picking. Further development of both the hardware and the stereo vision algorithms are required. Once the hydroponics trials are underway an image library will be captured that will be used to truth the stereo vision algorithms.

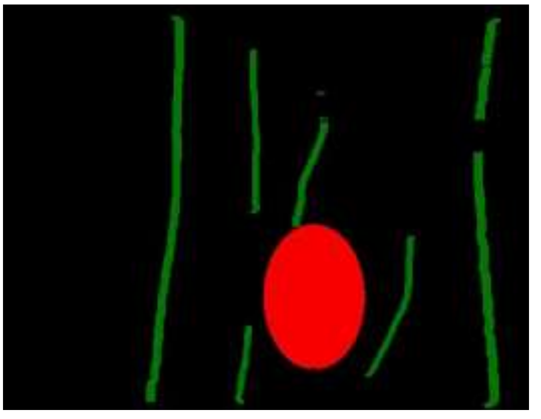

Figure 4: Three dimensional rendering of strawberry and peduncles using stereo vision.

Grading Vision System: The trials demonstrated that under the correct lighting conditions, blemishes such as mould can be detected (see Figure 5). Although the trials were positive, the development of blemish detection is at an early stage and algorithms for a wide range of blemishes from misshapen fruit through to insect damage still need to be devleoped.

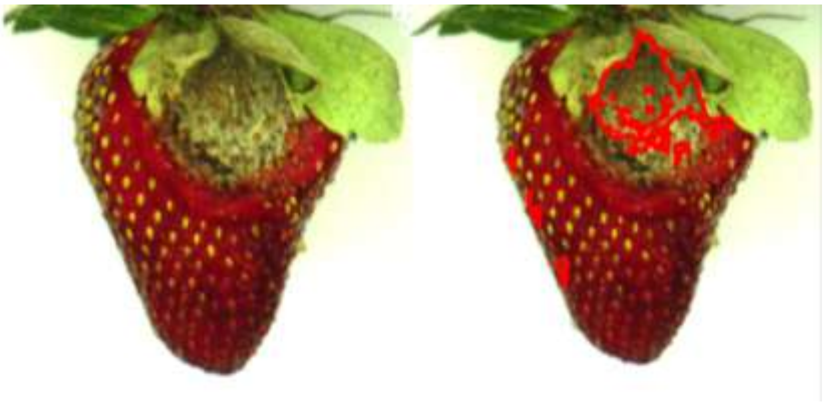

Figure 5: Raw image (left) with detection and highlighting of blemish (right).

Weight estimation:

Images of the three profiles of each fruit were centred on the centreline and a convex hull generated to estimate the volume (see Figure 6). While these estimates of the weight based on volume are not very accurate on a per fruit, the estimates over a full punnet of fruit are normalised. While the weight estimation methodology is at a the concept stage, the trials indicate that the estimates based on volumes have been more accurate than random samples of human packed punnets which tended to exceed the target weight range.

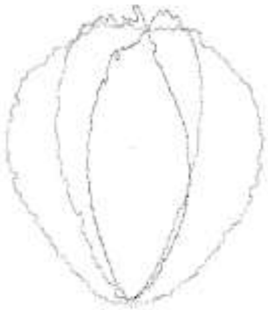

Figure 6: Rendering of weight estimation.

Rotating Growing System: The slab for the Rotating Growing System was laid (see Figure 7) and the Rotating Growing System has been erected, power supplied to site and drive system and trough supports assembled (see Figure 8). Several issues that were resolved included a seized sprocket, drive chain replacement and bent troughs. Three phase power has been installed with a motor controller. The rotating growing system has been commissioned and is now operational.

Figure 7: Site preparation and pouring of the slab.

Figure 8: Assembly of the Rotating Growing System.

Greenhouse: The greenhouse to house the Rotating Growing System was built around the Rotating Growing System as it would have been very difficult to erect the Rotating Growing System inside the greenhouse. This structure has successfully been built (see Figure 9).

Figure 9: Erection of greenhouse.

Hydroponic system: A pump, hydroponics tanks, hydroponic troughs, substrate and drippers have been procured.

SCARA robot arm: A SCARA robot and controller has been procured (see Figure 10). This industrial robot offers not only high performance (high speed and high speed) but is also robust and capable of millions of cycles with minimal service requirement.

Figure 10: Epson C3 6 axis robot arm and Epson RC180 control unit.

A concept design for the chassis has been completed (see Figure 11).

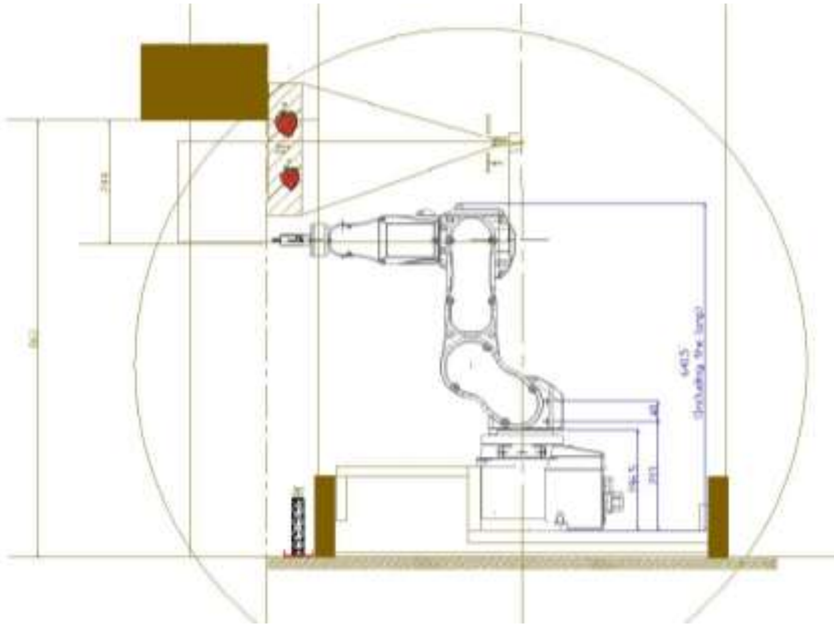

Figure 11: Chassis concept design.

Revised Machine Vision: A revised machine vision and lighting design was developed (see Figure 12).

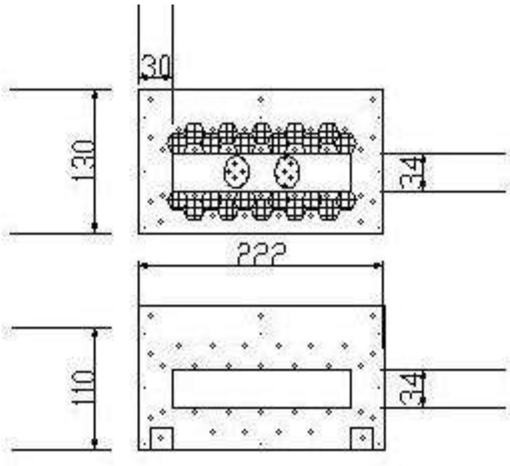

Figure 12: Design of lighting plate for machine vision system.

Peduncle Detection: The simulated environment does not provide a good indication of the peduncle detection rate under actual growing conditions so an assessment of the detection rate has been deferred until the production system has produced fruit and an assessment can be made under actual growing conditions.

Discussion

1. Robotics

Robotic system that has been procured offers significant advantages over the system used in BS08014. These advantages include high speed, high precision, high accuracy and a long service life. This makes the robot suitable for 24/7 high speed harvesting for 365 days per year with minimal maintenance and service costs.

2. Improvement of fruit detection algorithm

Fruit detection has been improved with the move to stereo vision. The new algorithms allow the detection of the fruit independently of the movement of the Picking Head. This vastly increase the speed of picking over the previous mono-vision method used for BS08014 as detection no longer requires controlled movement of the Picking Head so the Picking Head can now take the quickest route to pick the fruit.

3. High density strawberry production in a controlled environment.

Research has been undertaken into high density strawberry production in a controlled environment. This entailed reviewing the literature, attending the North American Strawberry Growers Association Conference and speaking with experts in the field. The consensus of the experts is that some experimentation is unavoidable due to the unique response of each cultivar to each different environment. Experimentation will be required to determine such factors as preferred cultivars, plant spacing, cropping cycles and rotation speed of the growing system.

4. Strawberry harvesting robot.

The concept design for the strawberry harvesting robot has been developed from the original field harvester concept to a harvester for substrate grown fruit in a covered production environment.

5. Strawberry grading.

Progress has been made with sizing, weight estimation and blemish detection. Grading is still at the concept phase and considerable work is still required before these tools can be considered for use in a commercial environment.

Technology Transfer

During this phase of the development, only limited technology transfer was undertaken, as the phase was focused on developing the concepts and setting up the new strawberry production system. The technology transfer undertaken was limited to discussing concepts with interested researchers and growers.

Once the production system is operational during the next phase the focus will shift to technology transfer. The biannual Queensland Strawberry Growers Field Day is to be held at Sunray Strawberries in 2011 with the focus of technology transfer being demonstrations to growers and service providers during this event.

Recommendations

For segments of the Australian horticultural industry that are labour intensive, the rising cost of labour and growing labour shortages are a significant threat to their long term viability. Technology for production automation is at a point where the cost and implementation barriers to labour saving automation are dropping very rapidly. Investment in and nurturing of robotic harvesting technologies should be strongly encouraged.

Specifically, for the strawberry sector, the increasing risk-return profile of field strawberry production combined with the growth of imports means that the Australian strawberry industry must innovate in order to remain viable in the long term. The new strawberry production system that is under development addresses the risks to production and offers better returns to growers. It is recommended that the advantages of the new strawberry production system be demonstrated by bringing the system into production during the 2011 season.

The new production system requires multidisciplinary expertise that spans disciplines from agronomy to robotics. There are also related projects in other segments of the horticultural industry that are addressing similar technical challenges, It would benefit the development of the new production system and other similar projects if ways of fostering better cooperation across the industry and across disciplines could be found.

Magnificent is developing a strawberry production system that includes full automation of harvesting, grading and packing that will lead to improved labour use efficiency while also reducing the cost of production. Consideration should also be given to leveraging the knowledge gained in this project into other horticultural industries that face similar challenges.

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Appendix A: Research

Magnificent has kept abreast of production and robotic harvesting technologies through regular literature reviews, direct communications with key experts and by attending the 2011 North American Strawberry Symposium in Florida.

The visit to North America included visits to a number of hydroponics farms in the USA and Mexico to see the state of the art for hydroponic production in those countries. A lot was learnt as to how to manage hydroponic strawberries with similar climates and at similar latitudes to Australian growers.

Figure 13: Mexican hydroponic production systems.

Appendix B: Agronomy

In this section where there is no acknowledgement and the information is of a more generic nature it was obtained from *pers comms* or from one of these sources:

Kristien Foets, 2007. De aardbeienteelt, Cursus voor het secundair tuinbouwonderwijs.

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Genetics

Strawberry plant genetics are tightly linked to yield and profits and thus require careful consideration. The performance of each cultivar depends on the local climate with solar radiation (latitude) and temperature having the biggest impact. The optimal genetics for the new production system will not necessarily be the same genetics as the genetics required for field production at the same location, as the rotating growing system and covered production modify the micro-climate. There are three main categories of strawberry genetics, although the differences between these categories are increasingly blurred by modern breeding programs:

June Bearers: June-bearing varieties produce one large crop of berries in late spring to early summer. These varieties are typically grown at high latitudes and tend to be less well suited to robotic harvesting due to the heavy fruit clustering that typifies these varieties.

Everbearers: Everbearing varieties produce two smaller crops. One in early summer and another in early autumn in summer growing regions. This category of genetics includes cultivars that are suited to the new production system.

Day-neutrals: Day-neutral berries, the newest category, can produce fruit continuously throughout the growing season. This category of genetics tends to be well suited to the new production system.

The cultivar selection for Australia will be largely determined by the location of the production system. For year-round production, cooler regions with high solar radiation are preferable. This is because heating a greenhouse is cheaper than cooling. Cultivar trials will be required at the chosen site. These trials should begin at least one season before full scale production is started.

Propagation: Interesting observations concerning runner propagation:

Second order daughter plantlets have been shown to produce “substantially greater fruit production” than plants derived from third order daughter plantlets. This difference was due to a delay in reproductive maturity of the third order plantlets (Selva - Hamann & Poling, 1997).

Plantlets transplanted earlier into a fruit production environment grew more and developed a greater number of branch crowns (Selva - Hamann & Poling, 1997).

To achieve greater early season yield plant stress factors such as bound roots must be minimized (Selva - Hamann & Poling, 1997).

Plug plants outperform fresh-dug, bare-root plants in an NFT greenhouse trials, because the plug plants flowered earlier and produced a greater number of fruit (Camarosa, Chandler & Sweet Charlie - Takeda et al., 1997).

Hydroponics

Recirculation: Hydroponic solution can either be recirculated ('closed' system) or the excess water can be run to waste ('open' system). With the open systems the risks of spreading infections in the hydroponic solution is considerably reduced. The infection that is mostly easily spread in a closed system is root-rot causing fungi. Closed system can be effective if water treatment of the recirculated water is included in the water recirculation system. For small scale trials where the cost of water treatment systems cannot be justified, an open system is preferable to avoid root-rot problems.

Bag culture: In bag culture, plants are grown in a soilless medium contained in lay-flat or upright polyethylene bags. Bag culture simplifies handling and can use a variety of growing mediums.

Media: The two essential ingredients of a good growing media mixture are a balance of proper drainage and water retention. Popular growing mediums include:

1. Perlite: Perlite is commonly used with vermiculite (a 50 - 50 mix is a very popular medium), and is also one of the major ingredients of soiless mix's. The biggest drawback to perlite is that it doesn't retain water well which means that it will dry out quickly between waterings.
2. Coir: Coconut fiber (also know as cocopeat) is essentially a waste product of the coconut industry, it is the powdered husks of the coconut itself. Is a totally "organic" growing medium that offers top performance in hydroponic systems for growing strawberries. There are many advantages - it maintains a larger oxygen capacity than rockwool, yet also has superior water holding ability over rockwool. Coconut fiber is also high in root stimulating hormones and offers some protection against root diseases including fungus infestation.
3. Vermiculite: Vermiculite is most frequently used in conjunction with perlite as the two complement each other well. The major drawback of vermiculite is that it retains too much water and can suffocate the roots of plants if used alone.
4. Growool/Rockwool/Stonewool (Cutilene): Rockwool is capable of holding a large amount of water. This creates an additional protection for situations, when water is not supplied. Up to 18 % of air is retained so there is a very little risk to overwatering when using rockwool. Rockwool particles and fibres can pose a serious health danger for human lungs.

5. Sponge: Newer type of sponge developed by Dunlop Australia is hydrophilic (water absorbent).
6. Oasis cubes. A very popular medium for use when growing from seed or from cuttings. This product has a neutral pH and retains water very well.
7. Nutrient Film Technique (NFT). NFT has been used to grow strawberries. An issue that has been identified with NFT in that as the root mat thickens and becomes more dense, the flowing nutrient solution tends to move over the top and down the outer edge of the root mat, reducing its contact with the entire root mass. This may eventually lead to flooding and root death. For NFT a channel width of at least 15 cm is advised.

From the literature and visits to hydroponic growers in Mexico, Florida, California, Netherlands, UK and Spain, coir is clearly the preferred medium for hydroponic strawberry production.

Table 1: Evaluation of 2 growing mediums and 3 nutrient programs in Florida (cultivar: Camarosa); Hochmuth, 2006.

	Yield (lbs per plant)							
	Total Yield	Early Yield	Dec	Jan	Feb	Mar	Apr	May
Media								
Perlite	0.88	0.18	0.01	0.17	0.18	0.27	0.20	0.05
Peat Mix	0.97	0.17	0.00	0.17	0.18	0.35	0.21	0.06
	NS	NS	NS	NS	NS	NS	NS	NS
Fertigation Program								
Osmocote 15-9-11	0.94	0.16	0.01	0.16	0.20	0.31	0.22	0.05
Osmocote 16-8-12	0.94	0.17	0.00	0.17	0.20	0.33	0.17	0.07
Fertigation	0.90	0.18	0.01	0.17	0.14	0.29	0.23	0.06
	NS	NS	NS	NS	NS	NS	NS	NS

Pollination: Issues with pollination by bees inside of greenhouse structures have been reported. It is important that the roofing material does not exclude light at the wavelength that bees use for navigation. For the test greenhouse European honeybees will be used for pollination.

Pest & Diseases: In the controlled greenhouse environment, pests and diseases can be more easily managed. For example, weeds can be eliminated by using a sterilised substrate.

Good phytosanitary practices must be followed such as dipping the runners in a fungicide & insecticide solution prior to planting to limit the introduction of pests and diseases into the growing system.

Insect pest will be excluded by using screens although practically it is very difficult to completely exclude all insect pests. In the closed environment the balance between beneficial insects and pests can be more easily managed.

Fungi such as powdery mildew can proliferate under favourable greenhouse conditions (low irradiance, high humidity & low temperature). It is thus important that the humidity and especially the condensation point be carefully managed through the diurnal cycle.
Bacteria can also have a beneficial effect. Trials involving root treatment at the plug stage of a plant-growth -promoting-rhizobacteria (PGPR) resulted in an increased yield of more than 20%.
Another strategy to mitigate pest and disease problem is to keep the cropping cycle short. This means replacing the plants with new clean plants after a short cropping cycle. A short four month cropping cycle will be used for the new production system.

Flowering: The induction of flowering is an important consideration for covered production where 3 cropping cycles per year are required. Initiation of flowering immediately after the plants enter the covered production environment is required. To achieve this flowering initiation, suitable environmental conditions must be created in the greenhouse as required. Strawberries are adapted to diverse environmental conditions from the tropics to 70º latitude, so different flowering responses to environmental conditions can be found. Depending on the cultivar, strawberries can be induced to flower by photoperiods under a critical limit, or by various photoperiod and temperature interactions.

Photoperiod and low temperature conditioning induce precocity (early maturity/flower induction). Precocity induced in Sweet Charlie & Chandler with daylengths less than 14 hours and temperatures less than 15°C (Guttridge, 1985). Durner et al. (1987) trials with field dug Camarosa (16 hours dark for 14 days) advanced the harvest date by 3 weeks but the untreated plants produced more biomass and fruit.
The effects of photoperiod (12, 13, 14, 15 or 16 h), day temperature (12, 15, 18, 24 or 27 °C) and night temperature (6, 9 or 12 °C) and their interactions on flower and inflorescence emergence were investigated by exposing 4 week old runner plants of strawberry cvs. Korona and Elsanta during a period of 3 weeks. A daily photoperiod of 12 or 13 h resulted in the highest number of plants with emerged flowers. A photoperiod of 14 h or more strongly reduced this number, while no flowers emerged at a photoperiod of 16 h. Plants exposed to photoperiods of 12 or 13 h flowered earlier and had longer flower trusses. A day temperature of 18 °C and/or a night temperature of 12 °C were optimal for plants to emerge flowers and resulted in the shortest time to flowering. A night temperature of 6 °C strongly reduced the number of plants that emerged flowers, especially when combined with lower day temperatures. Photoperiod and temperature had no effect on the number of inflorescences, all flowering plants produced on average one inflorescence. The number of flowers on the inflorescence increased with decreasing day temperature and when photoperiod was raised from 12 to 15 h. In general, 'Korona' was more sensitive to photoperiod and temperature as 'Elsanta', and had a lower optimal day temperature for flower emergence. (Norwegian Institute for Agricultural and Environmental Research, Horticulture and Urban Greening Division, Bioforsk Vest Sœrheim, 4353 Klepp St, NORWAY).

The University of Florida has a patent on a method for conditioning containerized, vegetative strawberry plants to induce early flowering upon transplantation (US patent 5444179).

Japanese research has indicated that the critical photoperiod for flower bud initiation of everbearing varieties is from 13 to 14 hours (Nishiyama et al., 2006). 14 days of short days (16 hours darkness) advanced the harvest date of Camarosa by 3 weeks.

Nishiyama et al., 1998, found that the everbearing strawberries flower at day (6 to 18:00)/ night (18 to 6:00) temperatures of 20/15°C and 25/20°C.

Discretionary short day cultivars (such as Sweet Charlie and Chandler) require daylengths less than 14 hours and temperatures less than 15°C to induce flowering (Darrow, 1936 & Guttridge, 1985).

Plants from which all mature leaves had been removed to leave only two immature leaves flowered in longer photoperiods than intact controls, and conversely plants bearing only three fully mature and no immature leaves required a shorter photoperiod for flower initiation than intact plants. The results provide evidence that the photoperiodic control of flowering operates through a flower inhibitor produced in the leaves (P. A. THOMPSON and C. G. GUTTRIDGE; 1960. The Role of Leaves as Inhibitors of Flower Induction in Strawberry, Annuals of Botany).

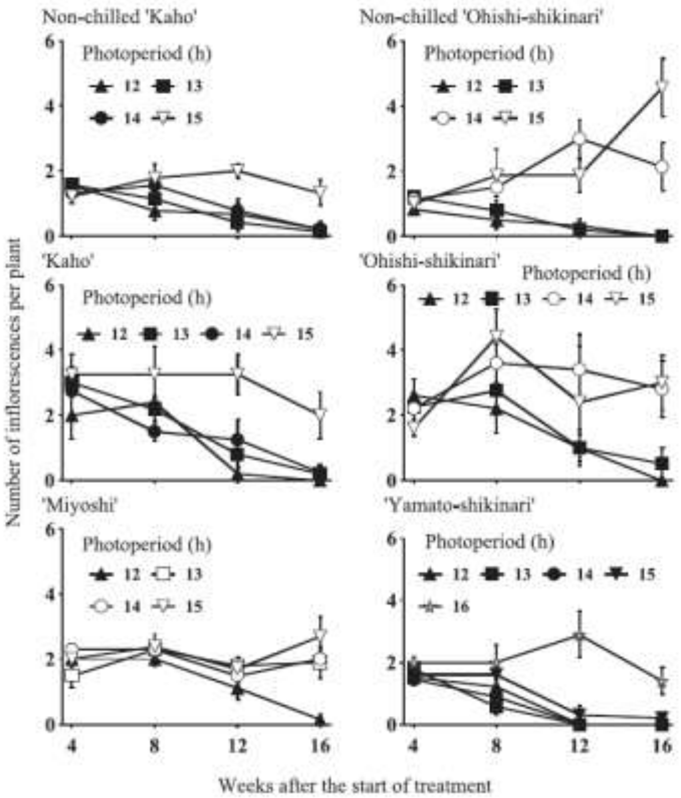


Figure 14: Effect of photoperiod on the number of inflorescences per plant grown at 30/25°C. Data are shown as averages of every 4-week period. Vertical bars represent SE (Nishiyama et al., 2006).

Leaf management: Braun and Garth (1986) found that number of leaves in strawberries cv. Olympus and Tillikum was reduced by soil application of paclobutrazol. Paclobutrazol affects petiole length via inhibiting gibberellin biosynthesis so reduction in cell elongation occurs.

Paclobutrazol caused differential partitioning at photosynthetic assimilates so reduction of transmission of photosynthetic assimilates to leaf cause limitation growth of leaf (Yelenosky et al., 1995). Foliar application of paclobutrazol at dosages of 200-1000mg/l resulted in decreased of leaf area of strawberries (Hasse et al., 1989).

Table 2: Effects of 9 hour day preconditioning on harvest date and crown development for plug plants (F. Takeda).

			Crown	
Conditioning treatment	Cultivar	First harvest date	Number	Dry weight (g)
Natural	Camarosa	23 Feb	8.3	5.4
	Chandler	20 Feb	6.1	3.8
9-hour day	Camarosa	6 Feb	6.3	4.1
	Chandler	20 Feb	6.9	4.1

Table 3: Earliness to fruiting and yields for static vertical growing system (F. Takeda).

Cultivar	Location	First harvest date	Yield (g/plant)
Chandler	Top	12 Dec	282 ± 49[Z]
	Middle	29 Dec	164 ± 55
	Bottom	19 Jan	138 ± 45
Sweet Charlie	Top	7 Dec	181 ± 53
	Middle	14 Dec	188 ± 59
	Bottom	5 Jan	131 ± 26

[Z]Mean ± std. error.

Lighting & Covered Production

With covered production supplemental lighting can be used to maintain high yields through the winter months or on overcast days where or to increase yields and fruit size or to promote earlier fruiting (Gottdenker J, Giacomelli, G & Durner, E).

While much research has been done on photoperiod and grow-lights, a new and fast evolving field is the effect of coloured lighting on plant growth. As an example trials in the Netherlands showed that a yield increase of 8-12% for tomatoes is possible by filtering the NIR spectrum (Hemming, et al. 2006; Acta Horticulturae 711).


Figure 15: Blue & red LED grow lights: http://www.pb-techniek.nl/film_lemnis_youtube_UK.html

Appendix C: Waiting Beds

Waiting beds are used to ensure maximum utilisation of capital intensive growing systems. This is achieved by ensuring that the plants are at the production stage when they enter the growing system which makes it possible to grow multiple crops in a calendar year.

Figure 16: Dutch waiting beds (left) & Japanese waiting bed system (right).

Appendix D: Growing systems

Rotating growing system are not a new concepts. For example, a 1966 US Patent (#3432965) describes a rotating growing system (see Figure 17).

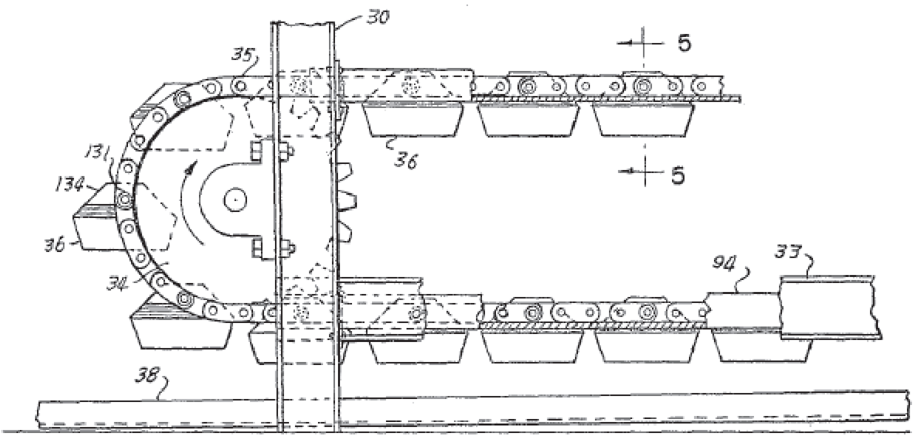


Figure 17: Diagram from US Patent 3432965 showing rotating hydroponic system.

A French patent (#23495912) dating back to 1976 describes a rotating growing system that is very similar to the concept required for the new production system (see Figure 18).

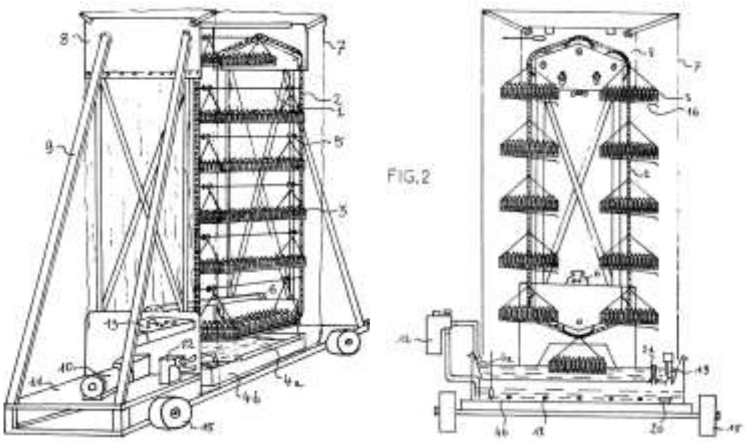


Figure 18: Diagram from French patent 23495912 showing rotating growing system.

There are several companies that market rotating growing systems. The first category is focused on systems that are suited to growing crops under grow lights with little or no natural light:

Omega Garden International: www.omegagarden.com
TerraSphere Systems, LLC: www.terraspheresystems.com
GI Grow: www.gigrow.com

The second category offer rotating growing systems more suited to using natural light:

A&B Hydroponics International: www.abhydroponics.com.au
Valcent Products Limited: www.valcent.eu

The above suppliers are an indicative list only, and there are other suppliers of rotating growing systems in addition to those described above, although these systems tend to be on a smaller scale (see http://www.volksgarden.com/).

Appendix E: Packing Shed Automation

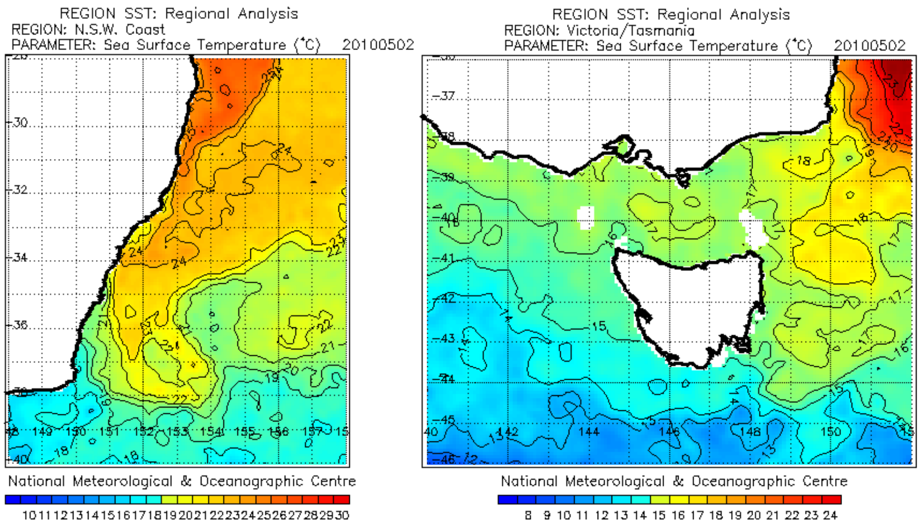
This appendix provides a list of suppliers of packing shed automation equipment. These suppliers have componenents that make it possible to fully automated the packing shed using commercial-off-the-shelf components:

Brimapack	www.brimapack.nl
Burg's Machinefabriek	www.burg-machinefabriek.nl
Edp	www.edp.com.au
Femc	www.femc.com
FGE	www.fge.co.nz
Fruit Tek	www.fruittek.com
Greefa	www.greefa.nl
ISO Group	www.isogroepmachinebouw.nl
Koat	www.en.koat.nl
Lakewood Process Machinery	www.lakewoodpm.com
Maf-roda	www.maf-roda.com
Van Wamel BV	www.vanwamel.nl
ZitroPack	www.zitropack.com

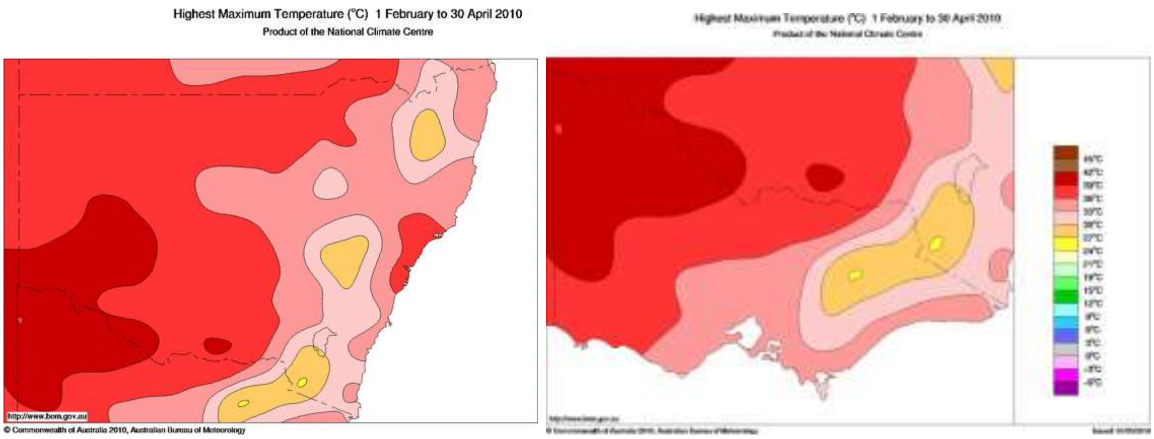
Appendix F: Site Location Selection

This appendix is an initial overview of potential site locations commercial production using the new production system. The objective is to find a site with sufficient solar radiation for year-round production with the minimum number of days with temperatures above 30 degrees. It is also advantageous if the location facilitates cost effective heating and cooling.

Oceans moderate the climate and are potentially a cooling source especially off Southern Victoria. It will likely be prohibitively difficult to obtain the necessary permissions to use the ocean as a cooling source?



Downside of site location near the ocean is salt from salt spray reducing greenhouse light transmission, accelerated corrosion and reduced heat units.



West of Geelong the temperature extremes are more moderate and deep inland water sources may be accessible, such as Lake Purrumbete. Lake Purrumbete is a volcanic crater more than 60 metres deep that would provide a great heat sink (if permissions can be obtained?). Well located on Princes Highway but less solar radiation that Glen Innes at 38˚17".

New England at over 1000 m has less severe heat extremes and is serviced by 2 highways. Higher solar radiation than Victoria.

Bunya Mountains at 1000m are at a lower latitude so should have more solar radiation. Tourism site reports the maximum temperature is 27 degrees. No accurate weather data is readily available. Transport to markets will be more expensive. More information is required. For example, cloud cover may restrict solar radiation.

Acknowledgments

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