Opportunities and challenges faced with emerging technologies in the Australian vegetable industry

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Food Chain Intelligence

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(Technology Platform 5: Emerging Technologies for Production and Harvest)

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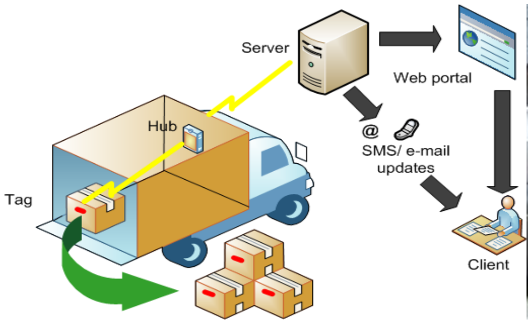

Opportunities and challenges faced with emerging technologies in the Australian vegetable industry.

(Technology Platform 5: Emerging Technologies for Production and Harvest)

Horticulture Australia Project Number: VG08087

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Purpose of Project:

This report was prepared as an outcome of Milestone 190 of project VG08087,"Opportunities and challenges faced with emerging technologies in the Australian vegetable industry". The project aims to provide a broad review of technologies that are influencing the competitiveness of the industry. This is the fourth of five reports to be developed during 2009-2010 and reviews novel production and harvesting technologies for vegetables.

Funding acknowledgements:

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Disclaimers:

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Media summary

The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the last of five analyses developed during 2009-2010 and reviews emerging technologies for production and harvest of vegetables.

Some key findings of this analysis were:

AGROCHEMICALS

A CSIRO study recently developed baseline scenarios for emergency plant pests (EPP) of interest to the vegetable industry. If these predicted scenarios become a reality, foreign disease invasions would cause over $2.4 billion in costs to the vegetable industry and the government. This represents about 7 to 12 times the investment needed to bring a new crop protection product to the market. Therefore, the ROI for R&D investment is positive from the perspective of potential losses.

AGRIBIOTECH

One of the most interesting applications of plant tissue culture is the establishment of plant biofactories to produce high value molecules. The engineering of edible plants may enable the delivery of vaccines through fruits, tubers, leaves or seeds.

SOILLESS PRODUCTION SYSTEMS

The vast majority of Australian farms operate with low to medium technology levels. A comparison between the productivity of protected cropping systems in UK and Australia revealed that the UK produces 4 times more vegetables under protected cropping practices than Australia, while the latter is 1.3 times more productive in field vegetable cropping. Australia is yet to reap the full benefit of protected horticulture.

AGRICULTURAL MACHINERY

Firms in the agricultural machinery sector lack the economies of scale, access to technology and low cost labour markets necessary to compete on the global stage. As a consequence, the use of imported equipment in Australian agriculture is estimated to be as high as 85% of the total equipment used.

HAL INVESTMENT

A large proportion of HAL R&D investment in the five platforms investigated has been dedicated to crop control aspects and irrigation. When compared with the expected investment strategy recommended in Future Focus, it is evident that the latter proposes a radical departure of current funding directions. Revisiting R&D priorities in Integrated Pest Management, Minor Chemical Use and Irrigation is therefore essential. For example, the projected costs of biosecurity threats to the industry by 2020 were not considered in the HI_LINK model used to develop the Future Focus strategy.

Further, projects related to crop control seems to be directed to measures such as training and management, driven by increasing regulatory pressures in chemical pesticides. The majority of projects in irrigation seem to focus on improving the efficiency of this operation in a range of crops. Projects on truly innovative technologies in these areas, *e.g.* those linked to precision agriculture and biotechnology, are less common. A balance between projects responding to current pressing needs and future needs in the vegetable industry needs to be achieved.

Technical summary

The objective of the project “Opportunities and challenges faced with emerging technologies in the Australian vegetable industry” is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the last of five analyses developed during 2009-2010 and reviews emerging technologies for production and harvest of vegetables.

Some key findings of this analysis were:

AGROCHEMICALS

As older pesticides continue to come out of patent, several companies are likely take advantage of existing approvals to specialise in the post-patent market. This likelihood increases if we take into account the significant lead times and costs involved in developing new chemical fertilisers: in the EU, developing a new pesticide and achieving its regulatory approval may take up to 10 years, costing €250 million. In Australia, only the approval phase can take between a year and 18 months. Recent efforts to decrease regulatory duplication by APVMA and FSANZ may mean that this time could be substantially decreased. Other factors that could decrease the R&D time are the high-throughput technologies added to the discovery of plant protection products, including genomics, proteomics, informatics, miniaturization and combinatorial chemistry.

A CSIRO study recently developed baseline scenarios for emergency plant pests (EPP) of interest to the vegetable industry. If these predicted scenarios become a reality, foreign disease invasions would cause over $2.4 billion in costs to the vegetable industry and the government. This represents about 7 to 12 times the investment needed to bring a new crop protection product to the market. Therefore, the ROI for R&D investment is positive from the perspective of potential losses.

The pressing need to research low cost alternatives to replace organophosphates and other chemical pesticides is highlighted by the review of the Australian Pesticides and Veterinary Medicines Authority (APVMA) on the registration status of chlorothalonil, dithiocarbamates, metaldehyde, phorate, rotenone, simazine cyanazine, terbufos, dimethoate and fenthion, under the Chemical Review Program. All of the chemicals mentioned are relevant to horticulture.

As the agrochemical industry is challenged by regulatory aspects (e.g. phasing-out of several pesticides) and the issue of soil depletion from fertilisers gains momentum, the agrochemical industry will likely turn to agribiotech solutions as a survival strategy. As the boundaries between crop protection and crop production become increasingly blurred, new chemical-based technologies for crop protection will slow down and biotech efforts in these areas will increase.

AGRIBIOTECH

A recent report reveals that at least nine GM horticultural crops are in the R&D and commercialisation pipeline, worldwide. Most of these developments relate to papaya, sugar beet, squash, capsicum, tomato and potato.

Despite these technical advances, the challenges faced by GM horticultural crops are related to social acceptance and this is clearly illustrated by the recent *bt* brinjal (eggplant) saga, discussed in this report.

Non-GM technologies include marker assisted selective breeding (MAS), micropropagation and tissue culture. MAS in particular can halve the time needed for traditional breeding techniques to bring a product to market. A recent example is the development of the world's most extensive collection of kiwifruit DNA sequences. The kiwifruit breeding programme is likely to benefit ZESPRI, which generates many thousands of seedlings every year. ZESPRI breeding programmes will be able to optimise times by "scanning" the seedlings to find out immediately which ones are likely to have the type of fruit wanted.

Micropropagation is commercially used in more than 30 developing and transition countries. Despite the successful transfer and widespread use of micropropagation, there is a scarcity of studies that evaluate its socio-economic impacts. There are only a few international examples, the most extensive ones being in China, Kenya and Viet Nam, on sweetpotato banana and potato, respectively. The reported increases in yield ranged from 30% to 100%.

One of the most interesting applications of plant tissue culture is the establishment of plant biofactories to produce high value molecules. The engineering of edible plants may enable the delivery of vaccines through fruits, tubers, leaves or seeds. In this way, cold chain requirements for the storage and the transport of purified recombinant products could be avoided, although the cold chain requirements to maintain the protein in the "carrier" -in this case, edible plant materials- needs to be investigated.

Although biopesticides constitute a relatively small portion of the pesticides market, their use reached about $30 million in sales in 2009. The growth in the use of biopesticides is attributed to the increasing regulation in the use of chemical pesticides, the promotion of integrated pest management, the pressure from export markets demanding chemical-free foods and the consumers' growing awareness to health and environmental issues created by chemical pesticides.

Both traditional pesticides and biopesticides are becoming direct competitors to disease-resistant transgenic products. Companies largely based on the development of agrochemical solutions for crop protection have started to feel the pressure of biotech-derived products.

SOILLESS PRODUCTION SYSTEMS

In the wake of environmental challenges and the need of increasing food security, soilless culture is being revisited as a low-cost alternative for locations where there is a lack of fertile soils and water scarcity. The largest industries in which soilless production dominates are greenhouse production of ornamentals and vegetables and outdoor container nursery production.

The value of the Australian hydroponic vegetable and cut flower sector has been estimated at approximately $1.3-$1.8 billion per annum in farm gate prices – equivalent to around 20-25 % of the total value of vegetable and flower production.

The vast majority of Australian farms operate with low to medium technology levels, lagging behind The Netherlands, US, UK and Canada, which have established best practice technologies and management systems in protected cropping systems.

The effect of levels of technology is illustrated in the comparison of the areas used for field and protected production of vegetables in the UK and Australia. These two areas are similar in both countries. However, the UK produces 4 times more vegetables under protected cropping practices than Australia, while the latter is 1.3 times more productive in field vegetable cropping. Australia is yet to reap the full benefit of protected horticulture.

Soilless systems are likely to play a significant role in the world's food production system in the near future. However, greenhouses with active heating and cooling are more capital intensive than field cropping. The amalgamation of new technologies in the field of climate control, sensors, vision technology and automation can provide breakthroughs in protected horticulture.

AGRICULTURAL MACHINERY

Firms in the agricultural machinery sector lack the economies of scale, access to technology and low cost labour markets necessary to compete on the global stage. As a consequence, the use of imported equipment in Australian agriculture is estimated to be as high as 85% of the total equipment used.

The usage of enabling technologies for mechanisation (e.g. computer and internet technologies) remains low in agriculture as a whole. In 2007-08, only 63% and 69% of fruit and vegetable farms in Australia were computer and internet enabled, respectively. Increasing the level of uptake of basic computer technologies is a pre-requisite for successful uptake of other ICT-based innovation, such as precision agriculture, mechanical and robotic harvesting and others.

Another barrier to innovation is the financial ability of farms to access innovative mechanical systems. Nearly 60% of vegetable growing operations produce an estimated value of $150,000 per year. For the majority of these organisations, purchasing a mechanical harvester costing between $100,000 and $450,000 which remains idle for the majority of the year would be an unwise decision. Collaborative schemes whereby mechanical harvesters are purchased through associations or cooperatives, so that the machinery cost and use is shared among participants, could be an alternative for small and medium size farm operations.

HAL INVESTMENT

From all the platforms investigated, production and harvesting seem to be the longest running and the topics that are likely to continue to be supported in the future, under current funding strategies. Almost half of the projects in this platform relate to crop control and plant health issues. The second theme in importance is irrigation. Very few projects are being developed for protected cropping.

When compared with the expected investment strategy recommended in *Future Focus* (Horticulture Australia Limited, 2008), it is evident that the latter proposes a radical departure of current funding directions of HAL for the vegetable industry.

Recommendations for future R&D funding include:

a) *Revisiting R&D priorities in Integrated Pest Management, Minor Chemical Use and Irrigation as presented in Future Focus.* In this report, we reviewed current challenges in these areas, including the review of commonly used chemical control agents by APVMA and the projected costs of biosecurity to the industry and Government by 2020. Such indirect costs were not considered in the HI_LINK model used to develop the *Future Focus* platforms.

Further, the focus of current investment in both crop control and irrigation also needs to be reconsidered. Crop control investment seems to be directed to "damage control" measures such as training and management, driven by increasing regulatory pressures in chemical pesticides. The majority of projects in irrigation seem to focus on improving the efficiency of this operation in a range of crops. Truly innovative projects in these areas, *e.g.* those linked to precision agriculture and biotechnology, are less common. A balance between projects responding to current pressing needs and future needs in the vegetable industry needs to be achieved in R&D funding.

b) *Collaborative funding.* Given that the R&D platforms with priority investment are consumer sciences, breeding, genetics, cold chain management and QA, other sources of investment to cover crop control and irrigation must be found. In this context, funding from organisations such as RIRDC, DAFF, DPI and state agencies could be discussed. Furthermore, HAL could look for opportunities to leverage R&D investment with organisations that are working in precision agriculture for broadacre crops. Innovations in biotechnology are less transferable. The development of this area relies on HAL funding and potential collaborations with organisations such as CSIRO and the Australian Plant Phenomics Facility.

c) *Integration of strategies for protected cropping.* It has been emphasized that protected cropping presents significant opportunities in vegetable production, in view of environmental impacts, land use and population challenges. The potential for growth in this industry is significant.

However, there is no specific distinction of vegetable levies paid on many crops grown through protected cropping. Field and protected production are both needed to develop a secure supply chain of Australian-grown vegetables and to face competition from imports.

Research on energy efficiency in greenhouse production and investment in innovative aquaponic and hydroponic systems would be of benefit to the industry. Also, innovative urban farming systems and the positive impact of growing vegetables near or in urban centres should be investigated.

d) *Biosystems engineering and ICT.* Australian-based innovation in agricultural machinery is in a state of decline and most innovations are occurring overseas. While importing agricultural equipment saves greatly in R&D investment, the trade-offs between these savings and the productivity achieved with machinery developed for conditions not prevalent in Australia need to be better understood. The need of a biosystems engineering approach to develop sophisticated agricultural machinery adapted to Australian conditions was highlighted. This topic also links to the need of developing ICT uptake at farm level. Developing communication and awareness about the needs of the modern horticultural industry in universities could positively influence the development of curricula that addresses these gaps.

Project Background

The vegetable industry is a truly multi-disciplinary business, particularly in the context of modern global supply chains. The industry draws knowledge from a variety of fields such as plant breeding and production, greenhouse technologies, irrigation, climate control, information technologies, product processing, packaging, logistics and consumer science, among others. Therefore, the growth of the vegetable sector is intertwined with the development and application of innovative solutions. The use of molecular biology to produce new enhanced (but still non-genetically modified organisms) cultivars, the introduction of pre-packed fresh vegetables and the development of track-and-trace systems that can improve transparency in food supply chains are examples of how emerging technologies can influence the Australian vegetable industry.

The project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" provides a broad review of current and emerging technologies that are influencing the competitiveness of the Australian vegetable industry. This review, carried out through the use of competitive intelligence (CI) analyses, provides a technology roadmap that shows: (a) where the Australian vegetable industry lies in the use of technology that benefits the competitiveness of the sector; and (b) what specific technological trends can affect the industry's competitiveness in the years ahead.

The application of CI techniques in this report was based on a two-staged approach:

I) An analysis of the technological state-of-the-art in the Australian vegetable sector, *i.e.* what technologies are been applied commercially (as distinct from pilot trials) during the production, harvesting, processing and distribution of vegetables. This analysis includes hurdles faced by 'first-movers' in the implementation of new technologies and the benefits reaped from the uptake of new technologies.

II) An analysis of emerging and potentially disruptive technologies with potential impact on the vegetables industry. The analysis included potential impediments for commercial implementation in Australia and potential benefits arising from the uptake of such technologies.

This project delivers competitive intelligence analyses in five key technological platforms relevant to horticultural industries:

(1) Supply chain and logistics systems.
(2) Technology for mitigation and adaption to environmental changes.
(3) Technology for food safety and quality assurance.
(4) Value addition processes (*e.g.* novel products and processes).
(5) Technology for production and harvesting.

The present report specifically delivers to the fifth technical platform: technologies for production and harvesting.

Introduction

Overview of vegetable production in Australia

The Australia vegetable industry encompasses 6,716 businesses that cumulatively produced 3.2 megatonnes of produce[1] with revenues of $3.3 billion in 2009.

The most representative vegetable products grown in Australia are presented in Figure 1.

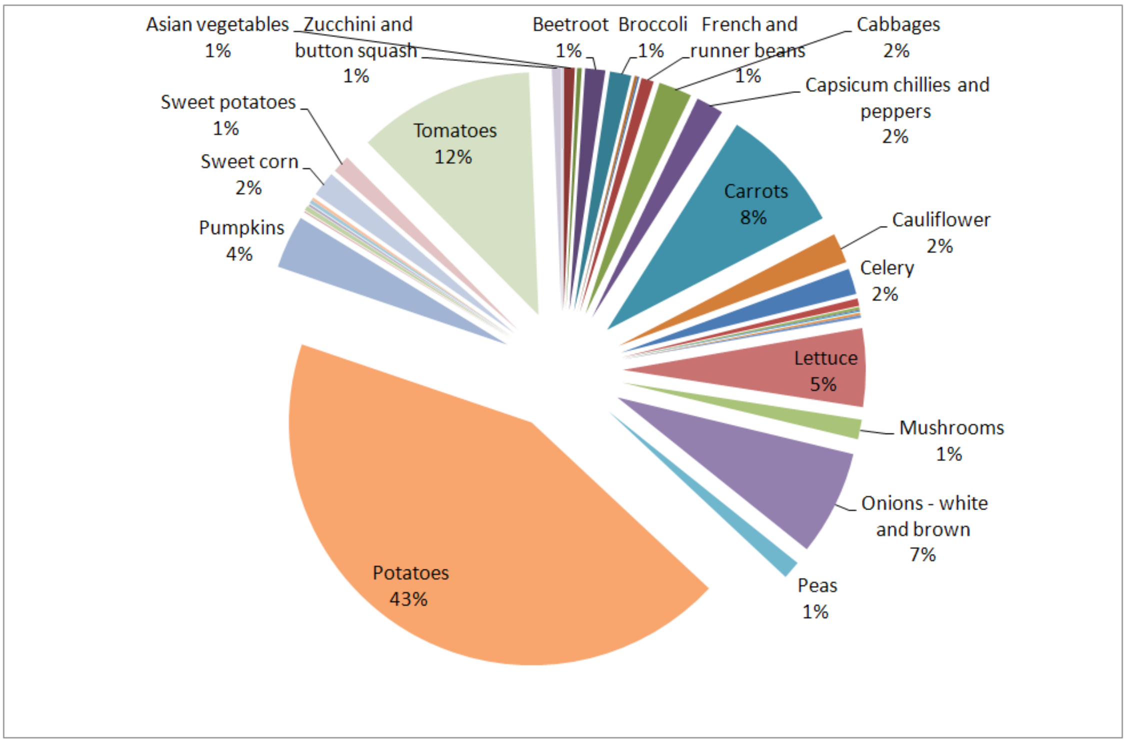


Figure 1. Proportion of vegetables grown in Australia by volume. Products representing less than 0.5% in volume have been omitted from this figure.

Vegetable growers are mostly located in Queensland (31.2%), Victoria (19.4%) and New South Wales (17.8%) (Riddell, 2009).

The type of production systems selected affects the selection of technologies appropriate of each system. For example, organic farming Organic farming is a form of agriculture that relies on crop rotation, green manure, compost, biological pest control, organically approved pesticide application and mechanical cultivation to maintain soil productivity and control pests, excluding or strictly limiting the use of synthetic fertilizers and synthetic pesticides, plant growth regulators, livestock antibiotics, food additives, and genetically modified organisms [2]. This exclusion means that other types of technologies that align better with the "naturalness" of the organic farming concept will be used.

[1] ABS, 2009
[2] http://ec.europa.eu/agriculture/organic/organic-farming/what-organic_en

Organic farming of vegetables

Organic fruit and vegetables are the most established part of the industry and represent about 47% of the total value of organic farms. Organic vegetables are the largest product segment by value, with annual revenues of $129.3 m. They are priced similarly to organic fruit, but the production of organic vegetables is about 60% greater than fruit.
The largest organic vegetables produced by volume are cucurbits (including pumpkins, zucchini and cucumbers), carrots, potatoes, brassica and leafy greens. By value, the largest organic vegetables are greens, cucurbits, herbs, alliums, and root crops.

Farms in this sector are predominately small, but there a few large operators. Organic vegetables held up relatively well under drought conditions due to their lower water requirements and their location on the eastern seaboard, which has relatively reliable rainfall (Walker, 2009).

Focus of this report

Only products and technologies not tackled in the previous three reports will be addressed in the present report. The technologies of interest are presented in Figure 2.

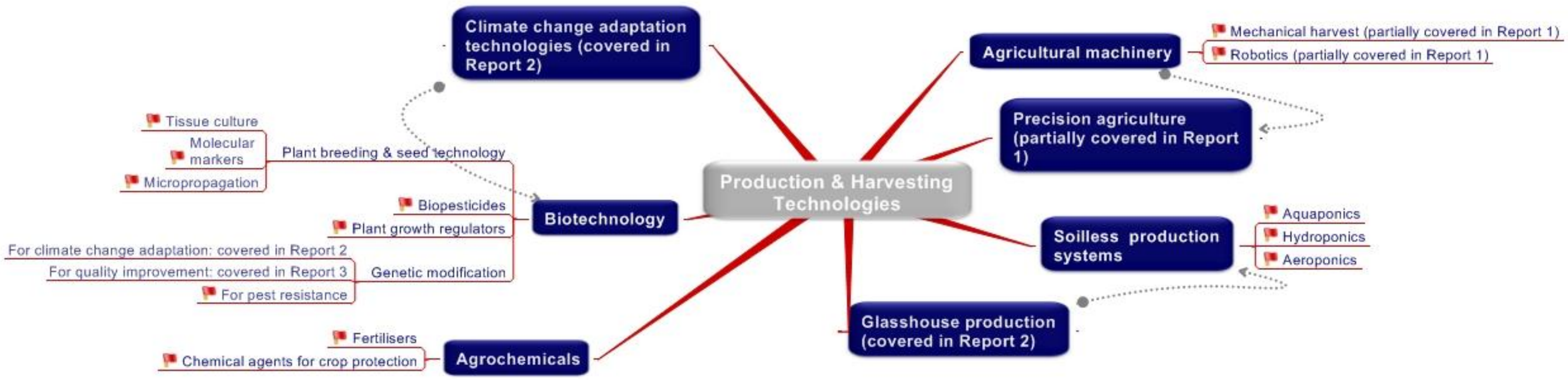


Figure 2. Production and harvesting technologies investigated in this project (indentified by the red flag).

Agrochemicals

Agrochemicals are an integral part of current agriculture production systems. However, there are two opposite trends in their use, each one related to a geographical region (Carvalho, 2010).

Developed countries, including European Union, USA and Canada, have approved new laws restraining the use of agrochemicals in recent times. This legislation aims at protecting consumers through a more thorough toxicological testing of compounds and enforcement of lower concentration limits for the residues tolerated in food and water (Harris, 2002).The European Union, through the Pesticides Framework Directive 2009/128/EC Directive (which became law in 2009), requires Member States to promote the use of alternative pest management systems, with priority to non-chemical methods and practices with lowest risks to health and the environment in fighting against pests. These alternatives include organic farming and integrated pest management, which entails natural pest control mechanisms. Control approaches used must keep pesticide intervention levels as low as possible, and must be used only when economically and ecologically justified[3].

Developing countries have a pressing need to increase the agricultural production and the use of crop protection chemicals seems a simple way for obtaining better crop yields. Therefore, developing countries continue using use cheap chemicals such as DDT, HCH, BCH They are also used because either their patents have expired and are easy to synthesize. This trend leads to the contamination of the environment, public exposure and higher residues in foods. The latter two risks are of international consequences when we consider the role of exports for many developed countries nowadays. In Australia, 20.4% of the fruit and vegetables consumed are imported (30% and 4.2% of all processed and fresh fruit and vegetables, respectively)[4]. While strict pesticide controls are applied in New Zealand, USA and Italy, restrictions in pesticide use in China and Thailand are more relaxed[5]. These five countries cumulatively represent 52% of the total imported processed horticultural products (Estrada-Flores and Larsen, 2010).

Another negative angle of agrochemicals that has been highlighted recently is the depletion of essential soil trace elements by excessive use of chemical fertilisers. Extreme cases are being seen in parts of Africa and in the US midwest dustbowls. There are also risks of water contamination (ammonia is highly toxic to fish) (Mactaggart, 2010).

Having said this, agrochemicals still have a significant market share in crop protection. More than three-quarters of the world's 20 leading agrochemical companies recorded sales increases of more that 15% in dollar terms in 2008. Table 1 shows the 2008 sales of the global top ten agrochemical companies.

[3] http://www.euissuetracker.com/en/focus/Pages/New-Pesticides-Framework-Directive.aspx
[4] http://www.ibisworld.com.au/pressrelease/pressrelease.aspx?prid=227
[5] http://www.foodweek.com.au/Default.aspx?tabid=53&ID=7016

Table 1. Top ten agrochemical companies in 2008. Source: Agrow World Crop Protection News. August 28th, 2009. No.574.

Company	Agrochemical Sales 2008 (US$ millions)	% change (2007-2008)
1. Syngenta (Switzerland)	$9,231	+26.7
2. Bayer (Germany)	$8,721	+16.9
3. BASF (Germany)	$5,013	+16.7
4. Monsanto (USA)	$4,996	+47.6
5. Dow AgroSciences (USA)	$4,535	+20.0
6. DuPont (USA)	$2,600	+9.8
7. Makhteshim Agan (Israel)	$2,335	+24.3
8. Nufarm (Australia)	$2,077	+41.3
9. Sumitomo Chemical (Japan)	$1,397	+15.6
10. Arysta Lifescience (Japan)	$1,168	+12.9

Fertilizers

Supply and demand factors

In the past years, there has been an increase in global fertilisers demand. This increase has been particularly high in the US, and has occurred in combination with a decrease in their production capacity. Moderate but strong growth was also recorded in parts of Asia, Africa, Eastern Europe and Latin America.

In the medium term, world fertiliser demand is projected to grow steadily. This is reflected in the positive percentage change of fertiliser sales in Table 2. Compared to the average consumption between 2004-05 and 2006-07, global demand in 2011-12 is expected to increase 2.6 % annually.

A recent inquiry on prices of fertilisers in Australia (Select Committee on Agricultural and Related Industries, 2009) highlighted the following global drivers leading to increasing demand:

- The economic need for increased yields in order to feed a growing population from limited arable land has driven this increased fertiliser consumption.
- Increased demand and high prices for agricultural commodities has led to an increased demand for fertiliser, as farmers take advantage of the agricultural price boom.
- As a result of record oil prices and new legislative requirements designed to address global warming concerns, there has been a substantial increase in the demand for biofuel crops (e.g. corn, sugar cane, palm oil). This has also led to an increase in fertiliser consumption.
- Income growth, especially in developing countries, is resulting in a shift in global dietary patterns away from traditional staples such as cereals and roots towards

livestock, fruit and vegetables. This shift affects the global demand for fertilisers in two ways: increased demand for livestock leads to increased demand for grains as feed stocks – which increases demand for fertiliser to produce that grain, as a flow-on effect. Further, a shift in demand from grain to vegetables and fruit crops leads to increased fertiliser demand, as the latter require greater fertiliser applications than grain crops.

- The increased demand for agricultural products in less arable land being available is being met by increasing productivity, primarily through the use of fertiliser.

Global fertiliser supply is being affected by:

- The finite nature of key fertiliser ingredients, such as urea, potash and in particular, phosphate rock.
- Supply disruptions in China, such as the 2008 earthquake in Sichuan province (a major production base for fertilisers and agricultural chemicals) and the increase in export duties by the Chinese government.
- The role of key market players and the high level of market concentration in the industry. The global fertiliser industry comprises a small number of large suppliers of fertiliser products. Between 80 and 85 % of the world's rock phosphate is controlled by five organisations.

The fertiliser manufacturing industry in Australia encompasses 49 businesses that cumulatively have annual revenues of $2.8 billion. Horticulture represents only 3% of the market of these companies (Figure 3). In terms of the total Australian consumption of fertilisers, horticulture represents 4% (Richardson, 2010a).

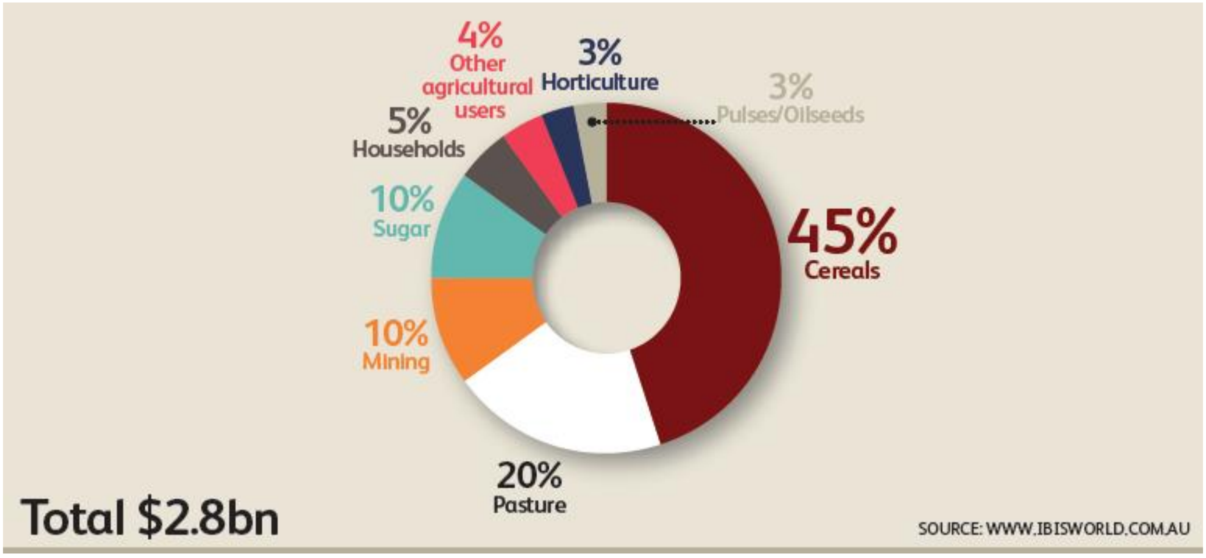


Figure 3. Market segmentation of fertiliser manufacturers in 2010.

The major Australian players in this industry are Incitec Pivot Ltd and Westfarmers CSBP Ltd.

Innovations in fertilisers

A search in Google for notes about discoveries, inventions and patents in fertilisers from 2000 to 2010 provided a volume of 191 postings, distributed as shown in Figure 4. This search essentially looks at references to dates in archived news articles over the years and it automatically creates a histogram of the relative counts. Although not an exact method, the histogram is a "Wisdom of the Crowds" data mining approach that reflects worldwide activity on the development of new fertilisers. In the past decade, the bulk of activity in this field was registered in 2005 and has been decreasing since.

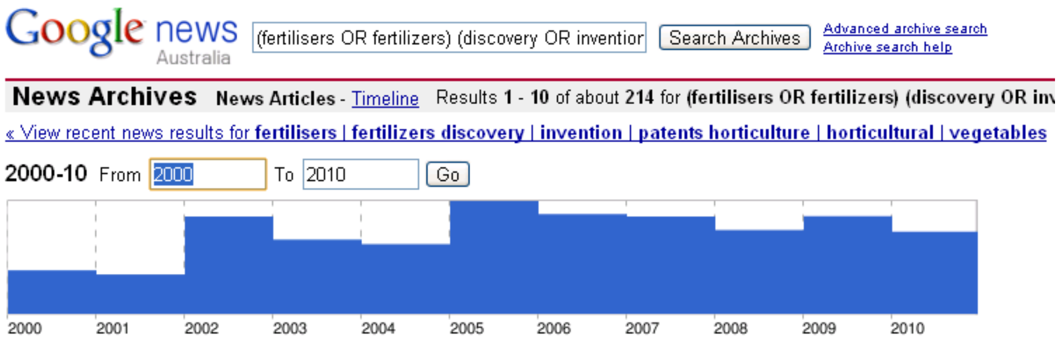


Figure 4. Website posts about discoveries, inventions and patents in fertilisers from 2000 to 2010, according to Google News.

Some specific developments in fertilisers include (Johnston and Norton, 2010):

Controlled release fertilisers (CRFs), which have been shown to significantly improve nitrogen (N) uptake by crops, while reducing N losses in high moisture environments. The two major types of manufactured CRFs are slowly soluble urea-aldehyde reaction products and coated fertilizers. Manufactured CRFs and processed natural organic materials (e.g. sewage sludge, animal manures), which contain slow-release nitrogen (SRN), are marketed in competition with lower cost, conventional (*i.e.* soluble) fertilizer products. The convenience and labour/ cost-saving advantages of CRFs have played an important role in their acceptance as economically viable substitutes for soluble fertilizers in non-agricultural markets (*e.g.* golf courses, other professionally maintained turf, and commercial ornamental nurseries and greenhouses). Because of CFRs' high prices relative to those for conventional fertilizers, their agricultural use has historically been mainly for high-value specialty crops such as strawberries, citrus, and certain vegetables.

Stabilised-nitrogen fertilisers (SNFs) include *urease inhibitors* and *nitrification inhibitors*. Urease inhibitors provide the best support to minimize N volatilization with surface broadcast urea. The urease enzyme in soil and crop residues converts urea to ammonia; slowing this conversion reduces the ammonia N loss by volatilization. Urease inhibitors temporarily slow down urease, providing about 10-13 days of stabilization prior to breakdown. However, this can provide improved safety to a farmer when surface applying urea ahead of forecast rainfall. Nitrification inhibitors help retaining N in the ammonium form, reducing leaching as well as denitrification.

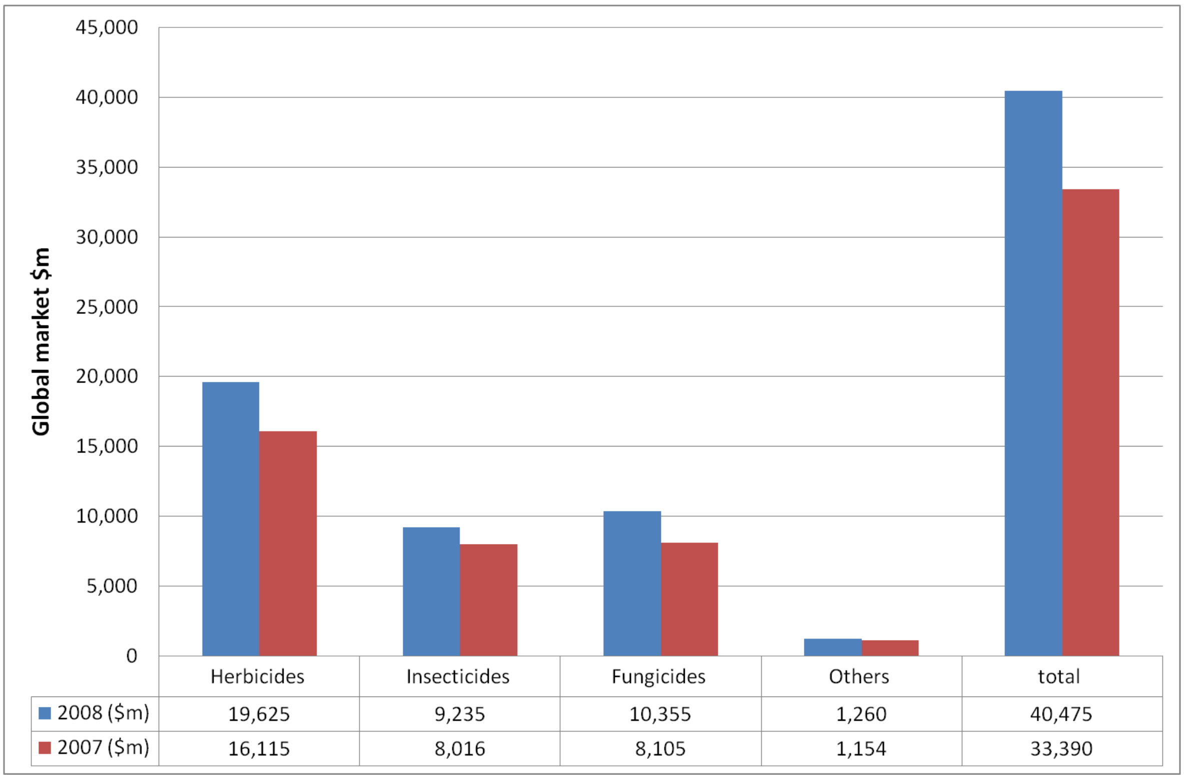
The second conversion from urea hydrolysis is the conversion of evolved ammonium to plant available nitrate. This process can be slowed using a nitrification inhibitor.

Formulations to manage low rates of micronutrients (iron, manganese, zinc, copper, boron and molybdenum). In Australia, vegetables are grown on a wide range of soil types, so it is important to understand the characteristics and constraints of each of these soils. To select a particular formulation, the grower needs to bear in mind which has been shown to work for a specific crop in specific soil types. The grower also needs to follow the application guidelines and timing carefully, can help in optimizing the crop response and yields (Pattison et al., 2010).

Chemical crop protection

Supply and demand factors

The global crop protection market per sector is illustrated in Figure 5.



	Herbicides	Insecticides	Fungicides	Others	total
2008 ($m)	19,625	9,235	10,355	1,260	40,475
2007 ($m)	16,115	8,016	8,105	1,154	33,390

Figure 5. Market growth of the global crop protection sector by product (US$m), 2007-2008.

The Australian market represents only 2% of the global demand. There are 110 companies manufacturing pesticides, herbicides and fungicides in Australia. Cumulatively, these companies produced $915 million in revenues during 2008. Horticulture represents 15% of the market of these companies (Figure 6).

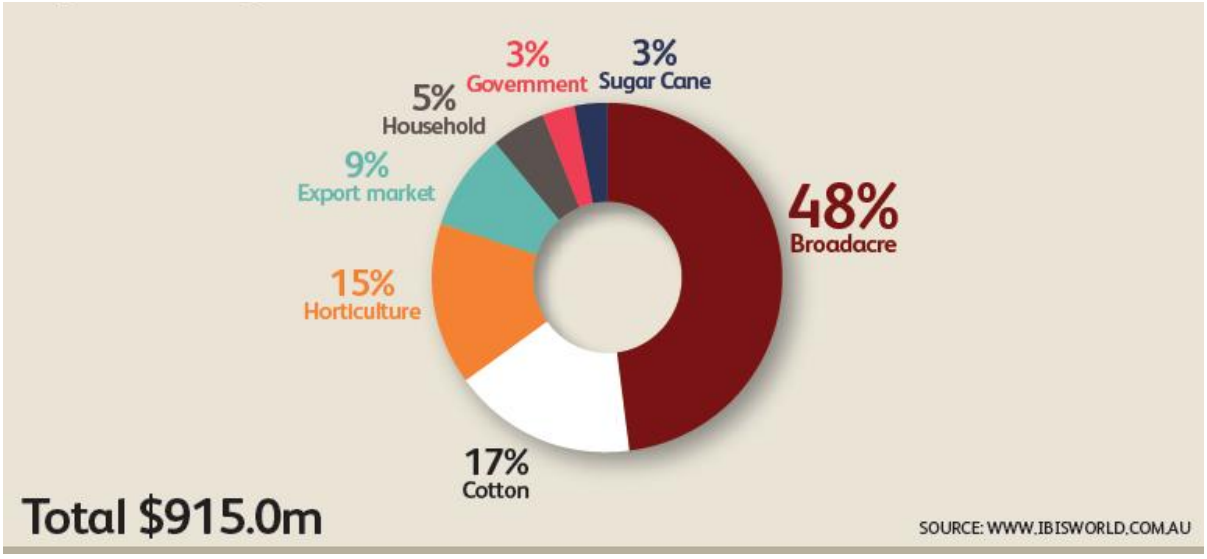


Figure 6. Market segmentation of manufacturers of products for crop protection in 2010.

The major players in this industry are Nufarm Ltd, Syngenta Crop Protection Pty Ltd, and Bayer Crop Science Pty Ltd.

Innovations in crop protection

Manufacturers of crop protection solutions have undergone a significant consolidation process during the last 15 years. In 1990, there were still 13 companies in this field with global R&D activities. There are now only six global players left, and together these make up more than 80% of the market (Kern, 2008). R&D in this field has become a highly complex and costly operation, as reflected in the decreasing number of innovations in active ingredients for crop protection, illustrated in Figure 7.

The crop protection market is undergoing a period similar to the explosion of generic pharmaceutical drugs. In the early 90's, large companies adopted the high-risk strategy of pouring funds into research efforts to discover new products they could patent. They had 20 years after filing for the patent to exclusively exploit those discoveries, after which the chemical compounds are available for anyone to use. As older pesticides continue to come out of patent, it is likely that several companies will take advantage of existing approvals to specialise in the post-patent market. This likelihood increases if we take into account the significant lead times and costs involved in developing new chemical fertilisers: in the EU, developing a new pesticide and achieving its regulatory approval may take up to 10 years, costing €250 million (Grossman, 2010). In the US, the costs are estimated in $200 million, with periods of 8-9 years for taking a new crop protection product to the market (McDougal, 2009). In Australia, only the approval phase can take between a year and 18 months.

Recent efforts to decrease regulatory duplication by APVMA and FSANZ may mean that this time could be substantially decreased[6].Other factors that could decrease the R&D time are the high-throughput technologies added to the discovery process of plant protection

[6] http://www.abc.net.au/rural/news/content/201006/s2928301.htm

products, including genomics, proteomics, informatics, miniaturization and combinatorial chemistry.

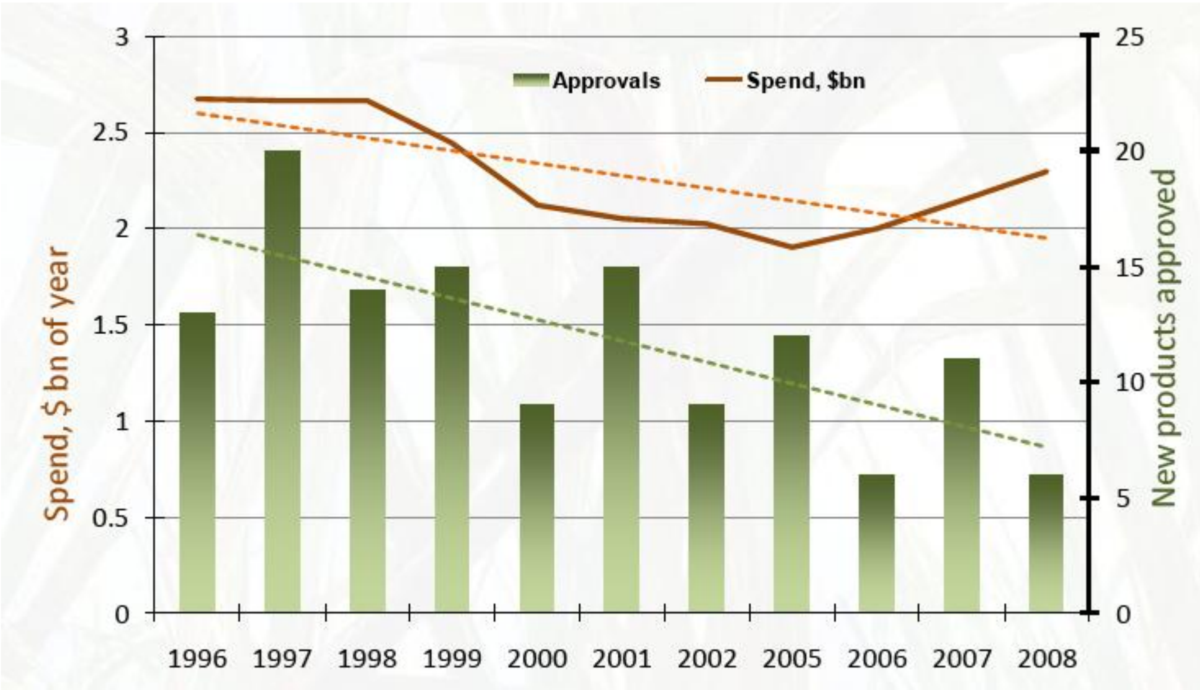


Figure 7. Number of new active ingredients approved and expenditure (US$ billion per year) in the period 1996-2008 (Lawrence, 2009).

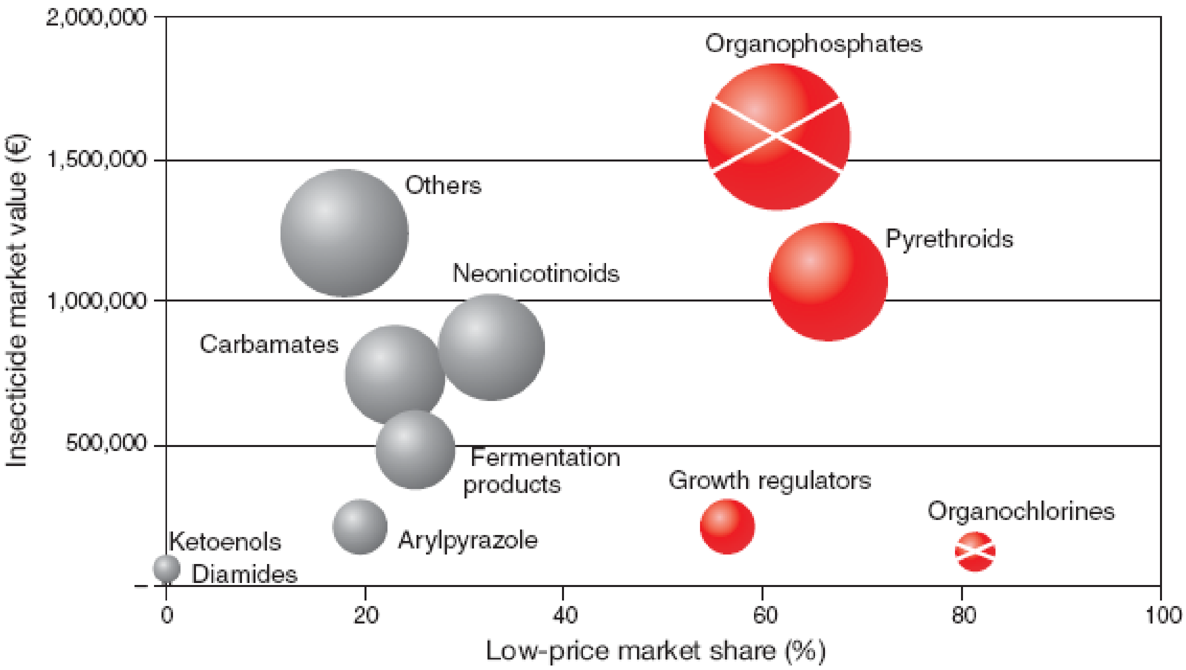


Figure 8. Various chemical classes of plant protection products in the low-price insecticide segment (Wirtz et al., 2009).Note that organophosphates (e.g. Dimethoate and Fenthion) currently face regulatory challenges in Europe and the USA. These products are currently under review by the Australian Pesticides and Veterinary Medicines Authority (APVMA).

Most innovations in chemical crop protection have focused in low-cost applications, since this segment represents around 40% of the global market. Figure 8 shows recent trends in crop protection innovation in the low-cost segment, which include:

- **Biopesticides.** Biopesticides are pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. This point is further reviewed under the heading "Agribiotech for the control of diseases and pests" in this report.
- **The development and use of synthetic low-cost pesticides,** in particular pyrethroids, to replace organophosphates and carbamates and avoid insect-related crop losses. While synthetic pyrethroids have been marketed for 30 years, pyrethroid mixtures and their presentations (e.g. as aerosols, dips, emulsifiable concentrates) have been adapted for modern application systems in horticulture. Potatoes, vegetables and flowers represent 20% of the total market for pyrethroids (Figure 9). Pyrethroids represent the third largest class of chemical insecticides after organophosphates and chloronicotinyl insecticides. A downside of its excessive application is the development of resistance, particularly in China and Pakistan.

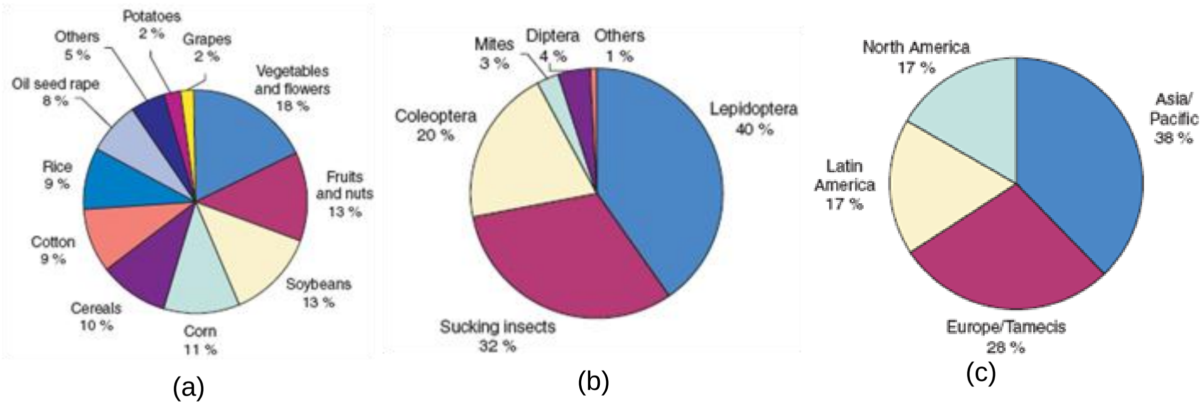


Figure 9. Global pyrethroid market in 2008, split by (a) crops, (b) pests; and (c) regions (Wirtz et al., 2009).

- **The use of predictive toxicology.** A project developed in the Imperial College London aims to develop a predictive model describing key molecular events in xenobiotic induced-liver toxicity, which would in turn lead to the development of a toxicological model for use in Syngenta's regulatory and research environments. The project applies Machine Learning theory and multi-"omics" data to better predict the safety of lead chemicals before they go into expensive toxicology programs. If successful, the model will be able to guide the choice of experimental design and reduce the cost and number of toxicological experiments for new pesticides. The project will identify mechanistic descriptions in model species, evaluate to what degree that can be applied to humans, and then apply these insights to optimize the human safety of new and current active ingredients [7].

[7] http://www3.imperial.ac.uk/syngenta-uic/research

The case for R&D investment in crop protection

A recent study (Cook et al., 2010) presented an evaluation of economic losses on the horticultural industry that would occur as a result of pest and disease incursions. These results were obtained through the use of a bioeconomic model that evaluated market costs (*i.e.* revenue loss), inspection costs, control costs (*i.e.* minimising crop damage) and eradication costs (*i.e.* the expenses of removing infested production units). All these costs were evaluated in a 30-year period, in a cumulative manner.

Tables 2 to 6 present baseline scenarios developed for emergency plant pests (EPP) of interest to the vegetable industry. These scenarios were developed using the best estimates available on probabilities of entry of each pest, establishment, infestation rates, average farm size and several other parameters.

In the predicted scenarios, the threat of foreign disease invasions is likely to cause over $2.4 billion in costs to the vegetable industry and government. This represents about 7 to 12 times the investment needed to bring a new crop protection product to the market. Therefore, the ROI for R&D investment is positive from the perspective of potential losses.

Table 2. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the broccoli industry (Cook et al., 2010).

EPP	Inspection ($ million)	Eradication ($ million)	Control ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	3	20	120	143	838
Cabbage moth	0	2	20	125	147	871
Texas root rot	1	1	0	18	20	149
Anthracnose	0	3	28	157	188	892

Table 3. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the cauliflower industry (Cook et al., 2010).

EPP	Inspection ($ million)	Eradication ($ million)	Control ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	1	10	73	84	386
Cabbage moth	0	1	10	74	85	376
Texas root rot	0	0	0	3	4	84

Table 4. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the lettuce industry (Cook et al., 2010).

EPP	Inspection ($ million)	Eradication ($ million)	Control ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	2	10	39	51	901
Cabbage moth	0	3	19	132	144	915
Texas root rot	1	1	0	6	8	159

Table 5. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the carrot industry (Cook et al., 2010).

EPP	Inspection ($ million)	Eradication ($ million)	Control ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage root fly	0	3	15	494	512	336
Cabbage looper	0	2	5	13	20	319
Cabbage moth	0	3	16	166	185	328
Crater rot	1	1	0	69	71	36
Texas root rot	1	0	0	0	1	9

Table 6. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the onion industry (Cook et al., 2010).

EPP	Inspection ($ million)	Eradication ($ million)	Control ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Onion fly	0	2	9	332	343	582
Cabbage moth	0	2	13	115	130	565
Cabbage looper	0	2	5	4	11	551
Cladosporium leaf blotch	0	2	6	0	8	582
Onion leaf blight	0	2	21	172	195	582
Onion bacteria blight	0	2	15	101	118	582

Challenges and opportunities for agrochemical R&D

Public R&D in the agrochemical area is conducted by universities, the CSIRO and State Departments of Agriculture and Primary Industry. Manufacturers also conduct some R&D, focussing on quality assurance for a range of soil and climatic conditions, crops and pastures.

As public R&D funding decreases in the agricultural areas, research on fertilisers is also likely to decrease. As Figure 10 shows, public investment in agricultural R&D has hit a plateau and the research intensity is in decline.

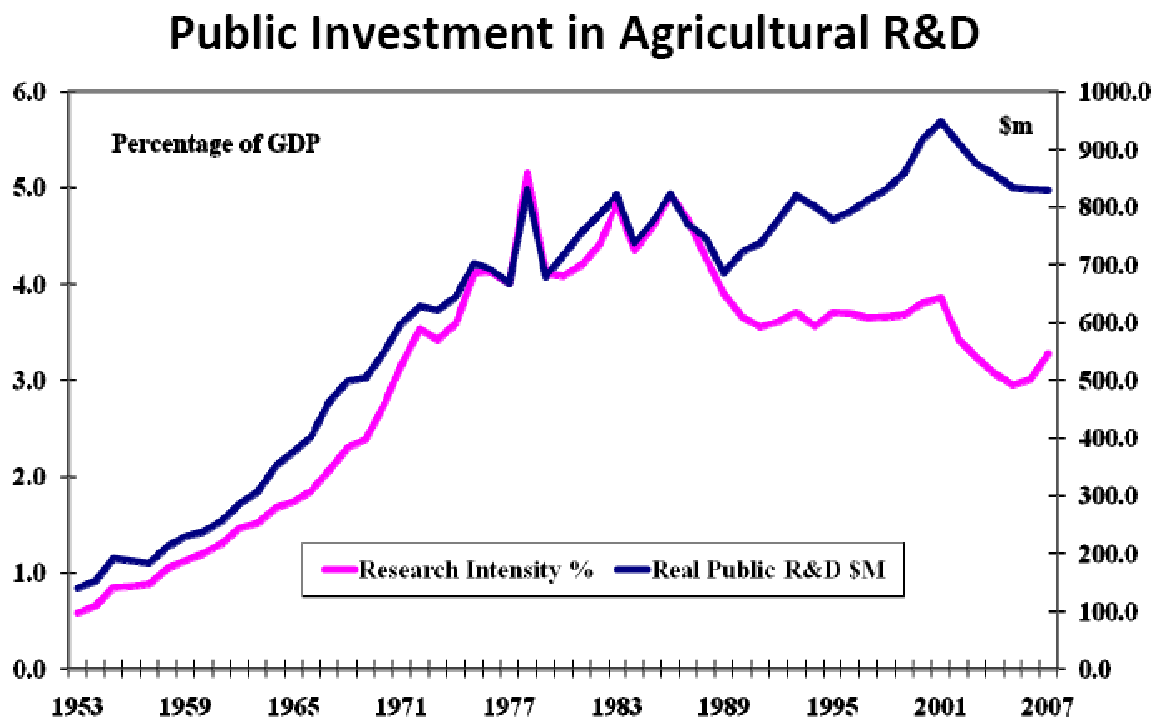


Figure 10. Public investment in agricultural R&D as a percentage of GDP and in real value terms ($m) (McMullen, 2010).

The investment by federal and states governments has decreased substantially in the past 12 years, while universities and businesses are increasing their share (Figure 11). However, the total investment has only increased $159 million in this period (or $13.3 million per year).

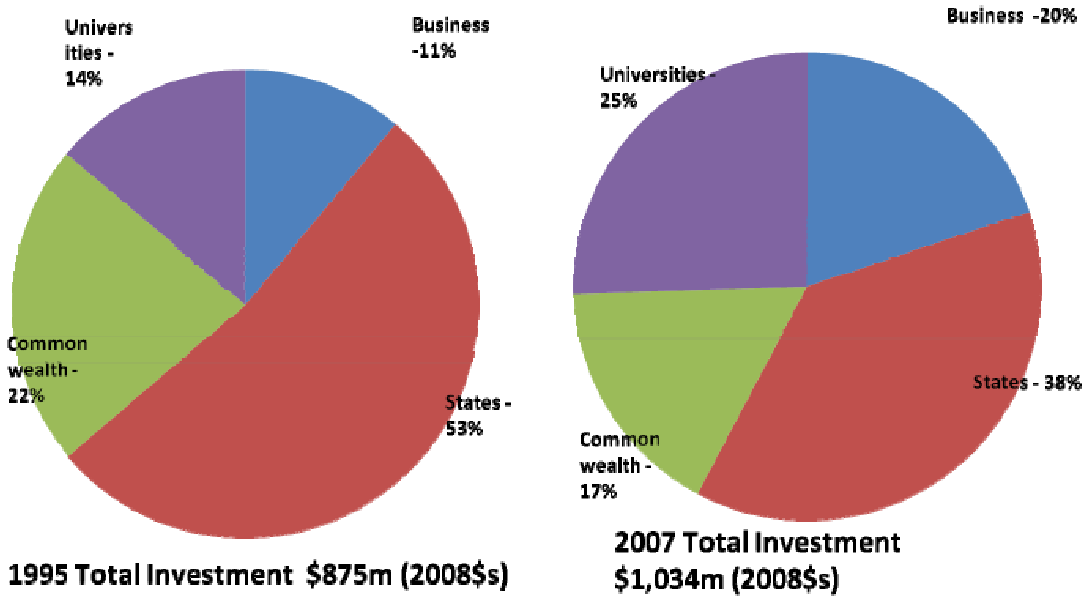


Figure 11. Shares of total R&D investment by sector (agriculture only) (McMullen, 2010).

On the whole, the global fertiliser industry is not a knowledge based industry, as financial pressures induced a cutback in research activities among many of the manufacturers of high volume, commodity fertilisers (Richardson, 2010a).

However, the development of pesticides is radically different. In this industry sector, there is an increasing emphasis on product innovation and the use of biotech as a basis of competitive differentiation. The need to optimise R&D and manufacturing costs has led to a strong industry consolidation and strategic alliances, as companies move to take advantage of new technological innovations. Changes in legislation and the need to protect patents of new products have also stimulated these developments. For example, Nufarm has formed alliances with Bayer, Syngenta, Monsanto, and Dow, among others (Richardson, 2010b).

As mentioned before, organophosphates and other chemical pesticides face increasing regulatory pressure. The Australian Pesticides and Veterinary Medicines Authority (APVMA) listed chlorothalonil, dithiocarbamates, metaldehyde, phorate, rotenone, simazine cyanazine, terbufos, dimethoate and fenthion for review under the Chemical Review Program [8]. Under this programme, the registration of these chemicals in the marketplace will be reviewed, considering new risks to safety and performance identified in the past years. All of the chemical mentioned are relevant to horticulture.

In regards to the status of dimethoate and fenthion, HAL and State Government agencies have funded additional research to find alternative treatment regimes, such as systems approaches. Given the expected economic losses in the case of foreign invasions presented in Tables 2 to 6, this investment will be crucial to protect the horticultural industry.

[8] http://www.apvma.gov.au/products/review/a_z_reviews.php

Australia is the only country still using dimethoate to treat fruit and vegetables after harvest[9]. Therefore, looking at the technologies that other countries have adopted to replace the use of this chemical is essential. The use of pyrethroids may be helpful in those crops that have not developed a resistance to its application. Integrated pest management and biotechnology-derived solutions are other alternatives. Further, the Department of Agriculture, Fisheries and Forestry is coordinating a process to prepare for the APVMA decision, which includes supporting a group of representatives from Commonwealth and State authorities, Plant Health Australia, Horticulture Australia, AusVeg and other industry bodies to provide advice and help to implement actions. Also, a guidebook of alternative treatments is being prepared and may be circulated in July 2010[9]. Irradiation, cold storage, heat treatment and a range of systems approaches[10] are being considered.

Another important area of research is the effect of vertebrate pests on horticulture. Although outside the scope of this report, assessments on the economic impacts of vertebrate pests in horticulture (Gong et al., 2009) are presented in Appendix A. These are mostly related to fruit production. The extent to which these pests affect the vegetable industry is unknown.

It should also be noted that, as the agrochemical industry is challenged by regulatory aspects (e.g. phasing-out of several pesticides) and the issue of soil depletion from fertilisers gains momentum, the agrochemical industry will likely turn to agribiotech solutions as a survival strategy. As the boundaries between crop protection and crop production become increasingly blurred, new chemical-based technologies to increase farm productivity and crop protection will slow down and biotech efforts in these areas will increase.

Biotechnology

Agriculture is one of the main areas of focus in the Australian biotech industry. The other area of importance is human health. This is reflected in Figure 12, which shows the split of products and services segmentation of the biotechnology sector.

9 http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/chem/faq_dimethoate_fenithon.pdf

10 A "systems approach" is the combination of several measures to decrease phytosanitary risks. An equivalent concept in food safety is "hurdle technologies".

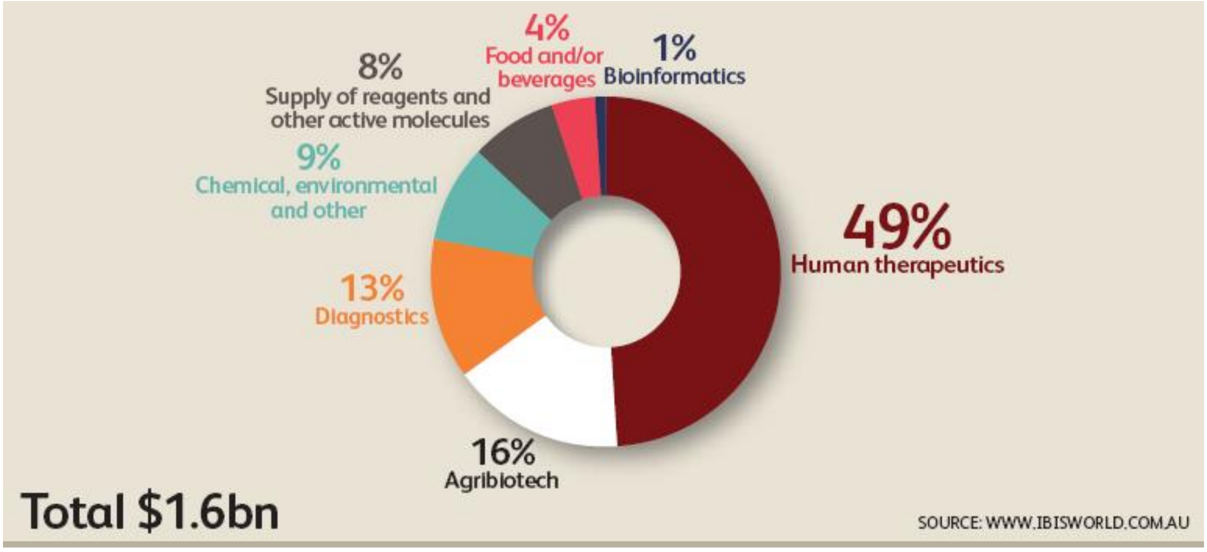


Figure 12. Products and services segmentation in the Australian biotechnology industry.

Agribiotech specifically includes the application of biotechnology to improve plant and animal production and/or to create new, high-value products (ACIL Tasman, 2008a).

Two previous reports (Estrada-Flores, 2009b, Estrada-Flores, 2010a) investigated the application of genetic modification (GM) technologies for vegetable production that address climate change adaptation and quality improvement, respectively. In this section we discuss agribiotech developments applied to increase the pre-harvest resistance of crops to pests and diseases.

Supply and demand factors

During 2008, the overall planted area of biotech crops rose by 10.3% to reach 296.4 million acres, worldwide. This in turn was a major contributing factor to the rise in value of the sale of biotech seed, which rose by 29.5% to reach US$9,150 million (Figure 13). However, little of this growth can be attributed to horticulture (Figure 14). The largest share of the biotech crop sector is attributed to herbicide tolerant crop varieties (mainly maize and cotton) which represented 51.8% of the value of the sector in 2008 (Figure 15) (CropLife International, 2009).

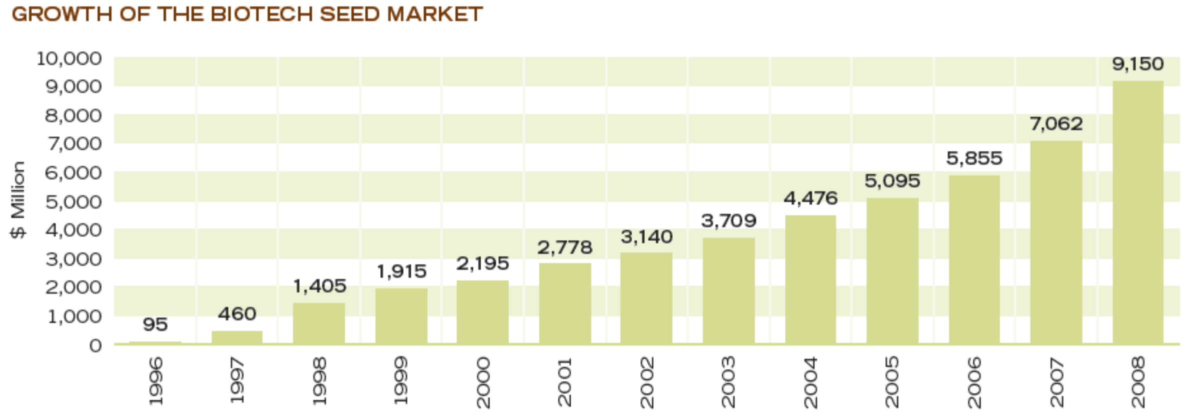


Figure 13. Growth of the global biotech seed market. Source: Phillips McDougal, 2009.

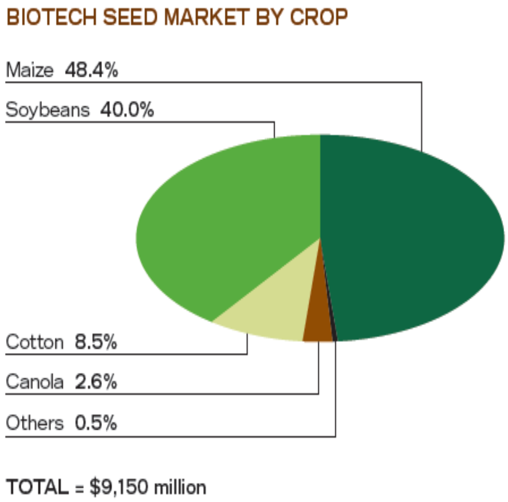


Figure 14. Biotech seed global market by crop. Source: 2009 ISAAA Report on Global Status of Biotech/GM Crops [11].

[11] http://www.isaaa.org/resources/publications/briefs/41/pptslides/default.asp

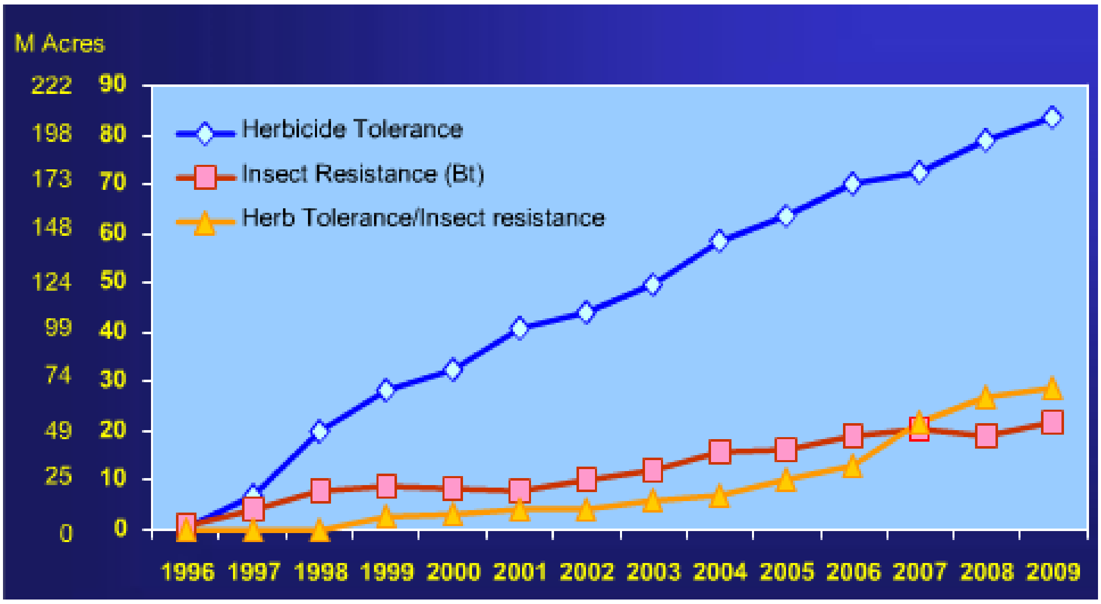


Figure 15. Global area of biotech crops by trait (million hectares, million acres), 1996-2009. Source: 2009 ISAAA Report on Global Status of Biotech/GM Crops

Innovations in agribiotech

Plant breeding and seed technology for enhancing resistance

Plant breeding is defined as the focused and purposeful manipulation of plant attributes, structure and composition to make them more useful for humans (Acquaah, 2007). Plant breeders specialise in different fields, of which we are mostly concerned here with resistance in vegetable crops.

There are three types of resistance breeding (Jacobsen et al., 2009):

(1) **Traditional breeding for major resistance genes** leading to vertical resistance with a specific spectrum, and/or for polygenes leading to partial, horizontal, or quantitative resistance with a broader spectrum.

(2) **Resistance breeding by transgenes**, which are genes coming from other organisms or which have a hybrid nature. The most important example is *Bacillus thuringiensis* (*Bt*)-based insect resistance, which has been transferred into more than 100 species. A refuge system and stacking of different *Bt* genes with different modes of action reduces resistance development of the target insect(s) involved.

(3) **Resistance breeding by cisgenes,** which are endogenous genes originating from the crop plant itself or from crossable species. Other terms for plant-derived transgenes include 'all-native DNA' and 'P-DNA'.

Differences between categories (2) and (3) should be evaluated in the context of the European legislative framework on GMOs. Some scientists argue that cisgenesis should be excluded from the GMO framework and regulated in the same way as traditional breeding (Schouten HJ, 2006, Jacobsen and Schouten, 2007). Counter-arguments maintain that there is no difference between resistance breeding by methods (2) and (3), given that cisgenic plants will be created using the same highly mutagenic plant transformation techniques used to create other transgenic plants[12]. Therefore, both transgene and cisgene-related technologies should remain classified as genetic modification. To date, no cisgenic plant has been put forward for authorisation under GM food legislation and the debate continues.

Resistance breeding by genetic modification

For a review of the current status of genetically modified horticultural crops to tackle climate change adaptation and cost-benefit aspects, the reader is referred to Estrada-Flores (2010). The development of resistance disease GM crops is also an adaptation strategy, in view of the predicted increase of insect pests and crop diseases thrive due to warming, increasing losses and necessitating greater pesticide use.

A recent report compiled a comprehensive list of currently marketed GM crops and GM crops in the pipeline, worldwide. Resistance breeding developments of interest to horticultural producers are presented in Table 7.

Table 7. Horticulture commercial GM crops related to pest/disease resistance (Stein .A and Rodriguez-Cerezo, 2009). Notes: Up to 2009, events marked with an asterisk (*) have not been authorised in the EU for any use. Events marked with a hash (#) have not been submitted for authorisation in the EU.

Developer	**Crop**	**Event name / genes**	**Trait**	**Unique identifier**
Cornell University (USA)	Papaya	55-1 * #	Virus resistance (to ringspot virus)	CUH-CP551-8
n/a (China)	Papaya	n/a * #	Virus resistance	n/a
Monsanto	Squash	CZW-3 * #	Virus resistance (to mosaic virus)	SEM-ØCZW3-2
KWS (Germany) and Monsanto	Sugar beet	H7-1	Herbicide tolerance (to glyphosate)	KM-ØØØH71-4
n/a (China)	Sweet pepper	n/a * #	Virus resistance	n/a
n/a (China)	Tomato	n/a * #	Virus resistance	n/a
Tecnoplant (Argentina)	Potato	SY230 * #	Virus resistance (to potato virus Y)	n/a
Tecnoplant (Argentina)	Potato	SY233 * #	Virus resistance (to potato virus Y)	n/a
In advanced stages of R&D:				***Commercialisation:***
n/a (India)	Potato	RB	Disease resistance (to late blight)	2011

[12] http://www.bioscienceresource.org/commentaries/article.php?id=9

Marker Assisted Selective breeding (MAS)

A non-GM application that can accelerate the traditional breeding process is MAS. This technology allows the identification of the location, purpose and activity of particular genes in plants. Further, MAS enables the sequencing, synthesis and manipulation of these genes for specific purposes. Gene expression profiling enables researchers to understand what genes act on certain desirable properties of plants (e.g. disease resistance, drought tolerance, quality traits), where they are located in plant tissues and the concentration of these (Innovation Dynamics, 2007).

The differences between traditional plant breeding and MAS are illustrated in Figure 16. A major advantage of MAS is the shortening of product development compared to traditional breeding, halving the time-to-market for improved seeds.

MAS allows plant breeders to pyramid different genes for the same expression into one variety. This is particularly useful to strengthen resistance to a disease, where adding different genes may raise the level of expression of resistance, also making it more durable[13].

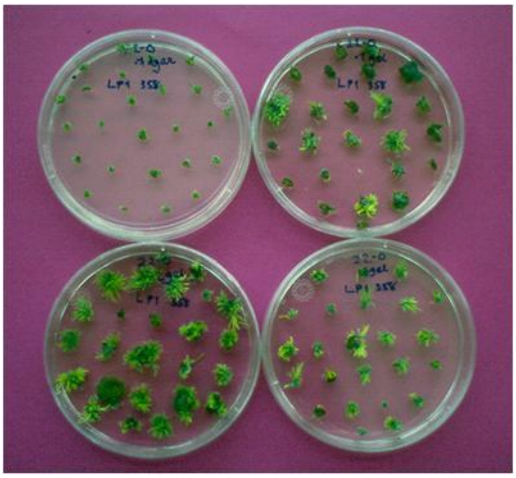
The most recent example of the application of MAS for horticultural varieties is the work developed at HortResearch and the New Zealand biotech company Genesis Research and Development Corporation Limited. These organisations released the world's most extensive collection of kiwifruit DNA sequences, comprising over 130,000 kiwifruit gene sequences.

The kiwifruit breeding programme is likely to benefit ZESPRI, which generates many thousands of seedlings every year. Without MAS, ZESPRI programmes would have to follow the traditional breeding times. With MAS, researchers can "scan" the seedlings and find out immediately which ones are likely to have the type of fruit wanted.

HortResearch and Genesis released a similar number of apple gene sequencing in March 2006, which are now part of HortResearch's apple and pear breeding programme.

Micropropagation and tissue culture

In conventional breeding methods, vegetative reproduction ensures that the new plants are identical to their parents. In potatoes, for example, the conventional method consists on planting the buds present on the tubers. As one tuber can give only a few new plants –one for each bud– several rounds of seed increase are needed to produce commercial quantities of potato "seed." This method also allows the transmission of disease-causing bacteria or viruses that may have infected the parent plant (Suslow and Bradford, 2002).



Micropropagation, or the mass production of identical plants from tiny buds of the parent plant,

[13] http://www2.dpi.qld.gov.au/fieldcrops/9020.html

can eliminate pathogens from the progeny plants while retaining the advantages of vegetative reproduction. It is one of the most widely used techniques for rapid asexual, in vitro propagation. This technique is relatively inexpensive and it also affords greater outputs of disease-free, high quality propagules[14], which provides an alternative to traditional propagation methods when the latter are unable to meet the demand for propagation material[15]. It also facilitates safer and quarantined movements of germplasm across nations.

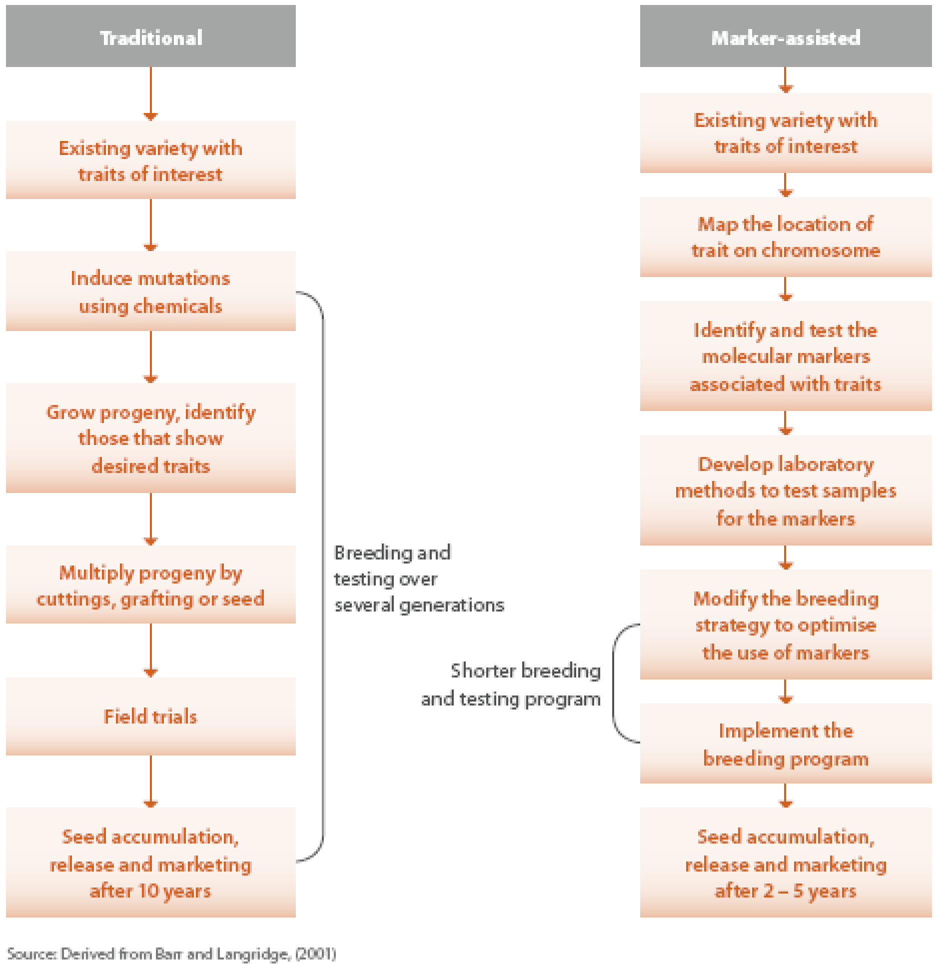


Figure 16. Traditional and MAS approaches to plant breeding technology (Innovation Dynamics, 2007).

Micropropagation is commercially used in more than 30 developing and transition countries. Despite the successful transfer and widespread use of micropropagation, there is a scarcity of studies that evaluate its socio-economic impacts. There are only a few international examples, the most extensive ones being in China, Kenya and Viet Nam, on sweetpotato banana and potato, respectively (Sonnino et al., 2009):

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[14] Any plant material used for the purpose of plant propagation.
[15] http://fbae.org/2009/FBAE/website/special-topics_biotech_in_horticulture_applications_of_biotechnology.html

- In the Shandong Province of China, the economic impact of micropropagated virus free sweetpotato was assessed in 1997. The results indicate that 80 % of the farmers took up the technology because of its proven ability to increase yields by up to 30 %; the IRR was estimated to be 202 %, with a NPV of US$550 million (assuming a 10 % real discount rate). By 1998, the annual productivity increases were valued at US$145 million, with an increase in agricultural income of the province's seven million sweetpotato growers by 3.6 and 1.6 %, in relatively poor and better-off districts, respectively.
- In Kenya, the commercial micropropagation of disease free bananas was adopted by over 500 000 farmers in 2004. The introduction of micropropagation was shown to offer relatively higher financial returns than traditional production.
- In Viet Nam, the introduction of improved high yielding and late blight resistant potato varieties and the subsequent adoption of micropropagation by farmers led to potato yields increasing significantly from 10 to 20 tonnes per hectare in 1996. The self-supporting plantlet production by the farmers made the seed more affordable and the rate of return on investment in this new seed system highly favourable. Micropropagation not only increased the farmers' yields and incomes, but also led to the creation of rural micro-enterprises that have specialized in the commercial provision of disease-free seed.

Tissue or in-vitro culture uses terminal shoots of leaf buds grown in an aseptic or sterile environment on agar gel or other nutrient-growing media to produce thousands of identical plants. The individual cells of a plant can be separated, multiplied, and regenerated into whole plants. In this way, thousands of copies of a single plant can be made and certified pest-free (Suslow and Bradford, 2002).

The Nursery & Garden Industry Australia and HAL have produced a technical booklet with the basic of micropropagation and plant tissue culture (McMahon, 2010). This is a good reference for those readers interested in knowing how they can apply the technology. The booklet is available through the NGIA website: http://www.ngia.com.au.

Apart of its obvious value in horticulture propagation, the most interesting application of tissue culture is the establishment of plants as "biofactories". One application of plant biofactories is in the production of compounds with pharmaceutical value. Plant tissues can be used as bacteria or yeast/mammalian cells have been used in the past to obtain high value molecules, which is why these technologies are also known as "molecular farming".

The advantages of plant materials with respect to conventional techniques (bacteria, mammal or yeast cells) are: i) lower production costs; ii) synthesis of functional proteins, similar to those produced in animal cells, absolutely free of animal pathogens; iii) easy scale-up and purification technology.

Plants can also be used for the large-scale production of several recombinant proteins such as antibodies and vaccine components. Furthermore, the engineering of edible plants may allow for the delivery of the recombinant protein (*e.g.* vaccines) through fruits, tubers, leaves or seeds. In this way, cold chain requirements for the storage and the transport of purified recombinant products could be avoided, although the cold chain requirements to maintain the protein in the "carrier" –in this case, edible plant materials– needs to be investigated. Additionally, the administration procedures by injection can also be avoided[16].

The production and commercialisation of plant-produced recombinant molecules must follow similar steps to those for conventional pharmaceutical products. It is therefore fundamental to cultivate these plants in greenhouses under a controlled environment and adapt the pharmaceutical quality assurance standards to deal with active ingredients that will have more inherent variability than normal active ingredients.

The use of vegetables as biofactories also encompasses the enhancement of health-related compounds naturally existent in vegetables. This topic was thoroughly discussed in the Report 4 of this series (Estrada-Flores, 2010b). Enhancement of vegetables to produce more health-promoting compounds does not necessarily entail genetic modification, as discussed in Report 3 (Estrada-Flores, 2010a). For example, simple acts such as shredding carrots and then maintaining these in controlled temperature storage have been shown to increase their antioxidant capacity[17]. Similar responses have been shown to occur with the phenolic contents of purple-flesh potatoes and other vegetables (Fernando Reyes et al., 2007).

Biopesticides

Biopesticides refer to biological pest control agents that are applied in a similar manner to chemical pesticides. These are commonly bacteria, but there are also examples of fungal control agents, including *Trichoderma spp*. and *Ampelomyces quisqualis* (a control agent for grape powdery mildew). Although biopesticides constitute a relatively small portion of the pesticides market, their use reached about $30 million in sales in 2009 [18].

A number of factors are leading the growth in the use of biopesticides in Australia:

- *Regulations to control the levels of chemical pesticides*: The growth of the biopesticides market in Australia reflects the low regulatory requirements of pesticides in the past years, as compared to the North American and European counterparts. However, in line with other segments of the chemicals industry, biologically-derived products will gain market share as governmental and consumer pressures combine to stimulate their uptake. The use of synthetic chemicals to control crop damage due to pests has been restricted worldwide due to their carcinogenicity, teratogenecity, high and acute residual toxicity, hormonal imbalance, long degradation period, environmental pollution and their adverse effects on food and side effects on humans (Brent and Hollomon, 1998, Dubey et al., 2007, Pant et al., 2007). Further, repeated use of certain chemical fungicides in packing houses has led to the appearance of fungicide-resistant populations of storage pathogens

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[16] http://ideas.enea.it/ideas-in-biotechnology-agricolture-and-helth%20prevention/molecular-farming
[17] http://news.discovery.com/earth/tortured-veggies-better-for-you.html, as reported in: Heredia, J. B. and Cisneros-Zevallos, L. 2002. Wounding stress on carrots increases the antioxidant capacity and the phenolics content. IFT Annual Meeting: Book of Abstract, Institute of Food Technologists, Chicago, IL, 180 p.
[18] http://www.frost.com/prod/servlet/market-insight-top.pag?Src=RSS&docid=204347216

(Dubey et al., 2008). In both Australia and New Zealand, the Maximum Residual Limits (MRLs) established for several pesticides are under review (see Agrochemical section in this report). This has created the need for alternative substances that can be used in conjunction with chemical pesticides, or as stand-alone solutions.

- *Promotion of integrated pest management (IPM):* the Australian biopesticides market has benefited from the initiatives undertaken to promote the recognition of IPM, a program aimed at optimizing pest control and lowering environmental impact through minimum chemical usage. The key components of IPM are the integral use of biopesticides complementing chemical pesticides, monitoring and timely application. Currently, although IPM has been acknowledged as an effective and feasible approach, it is considered a costly method toward pest control. Being still at early stages of its development, the IPM Accreditation Scheme is expected to play an increasingly important role in the promotion of biopesticides. Horticulture Australia has placed substantial efforts in developing minor chemical use practices since the late 1990's.
- *Pressure from export markets demanding chemical-free foods:* Although export markets account for a minor portion of the vegetable industry revenue, this is still a driver of change. With Western Europe and North America strengthening requirements on chemical residuals in the food, the exporters to these regions are forced to match these requirements.
- *Growing consumer awareness to health and environmental issues created by chemical pesticides:* supermarkets, the major buyers of horticultural products, have developed proprietary standards on pesticide residual levels in the food they procure. These requirements, as many other QA standards, are driven by consumers seeking healthier food. The Organic Federation of Australia, the industry body representing all organic foods producers (including horticulture, broad acreage, meat producers, and wholesalers), has actively promoted the fact that organic produce involves the replacement of chemical pesticides with biological pest control products.

Some commonly mentioned advantages of biopesticides are[19]:

- They are usually inherently less toxic than conventional pesticides.
- Many of these products do not have an MRL. For example, *Bacillus thuringiensis kurstaki* delta endotoxin[20] does not have an MRL.This biopesticide is used as an insecticide for cotton, pome fruits, stone fruits, grapes and vegetables. Garlic extract as an insecticide for fruit and vegetables is another example (Australian Pesticides and Veterinary Medicines Authority, 2010).
- Biopesticides are specific and target pest and closely related organisms, only. This is in contrast to broad spectrum pesticides that can affect organisms as different as birds, insects, and mammals.

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[19] http://www.epa.gov/opp00001/biopesticides/whatarebiopesticides.htm
[20] Encapsulated in killed *Pseudomonas fluorescens.*

- Biopesticides are often effective in very small quantities and decompose quickly, thereby resulting in lower exposures and largely avoiding the pollution problems caused by conventional pesticides.
- When used as a component of Integrated Pest Management (IPM) programs, biopesticides can greatly decrease the use of conventional pesticides, while crop yields remain high in most cases.

Some disadvantages are:

- Relatively more expensive than chemical pesticides.
- Limited availability.
- Low spectrum (they target specific pests).
- To use biopesticides effectively, users need to know a great deal about crop control and pest management.

There are three basic categories of biological protection systems:

1) **Microbial-based**, where microorganisms are used as the active ingredient. As per techniques used in resistance breeding by transgenes, *Bacillus thuringiensis*, (*Bt*) is the most widely used subspecies. Each strain of this bacterium produces a different mix of proteins, and specifically kills one or a few related species of insect larvae. While some *Bt*'s control moth larvae found on plants, other *Bt's* are specific for larvae of flies and mosquitoes. The target insect species are determined by whether the particular *Bt* produces a protein that can bind to a larval gut receptor, thereby causing the insect larvae to starve[21]. Examples of this category are presented in Table 8.
2) **Biochemical-based**, which are naturally occurring substances that modify the behaviour of pests, such as pheromones. Pheromone traps have been mostly used as a tool to monitor pests. Lately, pheromones have also been used for disruption of mating cycle. Small bits of rope impregnated with pheromones are strewn for dispensing this chemical in the field. The crop environment pervaded by pheromone confuses the females to the extent that their mating is disrupted, in spite of the fact that males are there in the field. The unmated females are rendered incapable of laying the eggs [22]. Examples of this category are presented in Table 8.
3) **Plant incorporated protectants**, which are pesticidal substances produced by plants containing added genetic material. For example, scientists can take the gene for the *Bt* pesticidal protein, and introduce the gene into the plant's own genetic material. Then the plant, instead of the *Bt* bacterium, manufactures the substance that destroys the pest. This category thus represents genetic modification technologies and are reviewed in the section "Resistance breeding by genetic modification" in this report. Examples of this category are presented in Table 7.

[21] http://www.epa.gov/opp00001/biopesticides/whatarebiopesticides.htm
[22] http://www.organicfarmingworld.com/organicpestcontrol.html

Table 8. Examples of microbial-based and biochemical-based biopesticides.

Type of biocontrol	Example	Reference
Microbial-based	A liquid formulation of *Pseudomonas fluorescens* strain Pf1 was investigated against *Fusarium* wilt of tomato. The combination of seed treatment, seedling dip and soil drenching of liquid formulation recorded the minimum disease incidence of *Fusarium* wilt on tomato under glasshouse (17.33%) and field (4.81%) conditions. In addition, the liquid formulation increased the tomato fruit yield compared to untreated control under glasshouse and field conditions.	(Manikandan et al., 2010)
	Biocontrol of *Rhizoctonia solani* and *Sclerotium rolfsii* on tomato by delivering antagonistic bacteria was investigated. In 2-year field experiments, two antagonistic bacterial isolates (*Burkholderia cepacia*, T1A-2B, and *Pseudomonas spp.*, T4B-2A) were applied to the soil by means of a drip irrigation system. Isolate T1A-2B reduced up to 58.33% and up to 63.8% the severity of the diseases caused by *S. rolfsii* and *R. solani* respectively; whereas isolate T4B-2A gave reduction of *S. rolfsii* and *R. solani* diseases severity up to 73.2% and up to 62.7%, respectively. The effectiveness of these biocontrol systems was comparable to synthetic fungicides, except for tolclofos-methyl which was the most effective treatment.	(De Curtis et al.)
	An insect-attacking virus (baculovirus) has been modified using rDNA techniques to produce a protein toxin from a gene originally obtained from scorpions. Field trials in the US on several vegetable crops have been proposed.	(Suslow and Bradford, 2002)
	A *Bacillus subtilis* strain is being applied in Serenade®, a product manufactured by BASF, against vegetable fungal diseases (*Botrytis cinerea, Erysiphe spp, Alternaria spp , Sclerotinia sclerotiorum , Rhizoctonia solani , Phytophthora infestans, Cercospora beticola, Pseudoperonospora cubensis, Sphaerotheca fuliginea*).	http://www.agro.basf.com/agr/AP-Internet/en/content/solutions/solution_highlights/serenade/bio-fungicide
Biochemical-based	The diamondback moth (DBM), *Plutella xylostella* (L.), remains a major pest of brassica crops worldwide. DBM has been estimated globally to cost US$ 1 billion in direct losses and control costs. Chemical control of this pest remains difficult due to the rapid development of resistance to insecticides and to their effect on natural enemies. The deployment of DBM-resistant brassicas expressing proteins from *Bacillus thuringiensis* could help to break the cycle of insecticide misuse and crop loss, but their deployment should be part of an IPM package, which recognises the constraints of farmers while addressing the requirement to control other Lepidoptera, aphids and other secondary	(Grzywacz et al.)

	pests.	
	Pheromone lures in sulfur free rubber dispenser / septa impregnated with specific pheromones for various species of insets viz. *Helicoverpa (Heliothis) armigera, Spodoptera litura, Pectinophora gossypiella, Earias vittella, Earias insulana, Scirpophaga incertulas, Plutella xylostella, Leucinodes orbonalis.*	http://www.innovativeagro.com/index.html

Both traditional pesticides and biopesticides are becoming direct competitors to disease-resistant transgenic products. Companies largely based on the development of agrochemical solutions for crop protection have started to feel the pressure of biotech-derived products. For example, Syngenta recognises the potential negative impact of the adoption of biotech-derived products as a risk factor to their operations, as they move towards the market of GM themselves:

> *"The adoption of the products derived through biotechnology could have a negative impact on areas of Syngenta's traditional crop protection business. This may not be offset, in whole or in part, by the opportunities presented to Syngenta's seeds and business development businesses, which are more actively pursuing products and traits developed through biotechnology. Crop protection accounted for approximately 80% of sales in 2008, whereas seeds accounted for approximately 20% of sales." (Syngenta, 2009).*

Plant growth regulators

Plant growth regulators (PGRs) are either exogenous growth regulators added to a field/media or plant hormones either added externally or developed by the plant itself. Their role is to modify the growth of a plant by altering its biochemical or physiological processes. If used at higher rates, some PGRs begin to show herbicidal activity.

Several researchers have shown the stimulatory effects of growth regulators on the vegetative growth and yield of plants. Examples include:

- The use of gibberellic acid to stimulate stem and petiole extension in rhubarb, celery and water cress (Thomas, 1976).
- The use of auxin or a mixture of gibberellic acid (GA) and kinetin for the treatment of radish and onion seeds to increase the germination of the seeds (Thomas, 1976).
- The use of tomato waste to promote growth in tomato seedlings. Tomato juice waste is rich in polysaccharides and was found to be a potent growth regulator (Suzuki et al., 2002).
- The use of commercially processed vermicomposts produced from food wastes, paper wastes and cattle manure, to increase the growth and yields of peppers. The byproducts of microbial activities in vermicomposts include polysaccharides and

plant-growth regulating substances such as auxins, gibberellins, cytokinins, ethylene and abscisic acid (Arancon et al., 2005).

Plant hormones play a crucial role in controlling the way in which plants grow and develop. They regulate the speed of growth of the individual parts and integrate these parts to produce the plants.

Well-known PGRs produced by the plants themselves are auxins, giberellins and cytokinins. This group is also known a "juvenile hormones". Maturing hormones include abscisic acid and ethylene[23]. The uses of ethylene and related chemicals (e.g. 1-MCP has been reviewed in Report 3 (Estrada-Flores, 2010a).

In 2008, a team of French, Australian and Dutch scientists discovered a new group of plant hormones, called strigolactones. This group of chemicals is known to be involved in the interaction between plants and their environment. Strigolactones are also crucial for the branching of plants [24]. Examples of the application of the newly discovered hormone are of importance to cut flowers and tomato plants with more or fewer branches. A joint patent application for the use of strigolactones to control the growth of plants has been filled by INRA (France) and the University of Queensland (Australia)[25].

Another application of PGRs aims to reduce the use of fertilisers through the improvement of nutrient uptake and utilisation by the plants. One of such products is Actiwave® (Valagro S.p.a.). Experiments performed on rocket grown in a floating system with standard nutrient solution showed that Actiwave significantly increased the nutrient uptake and nutrient use efficiency in all treatments. Further, it reduced the leaf nitrate content and increased chlorophyll and carotenoids in all treatments. The study concluded that the combination of hydroponics and biostimulants is a promising strategy for the greenhouse production of high-quality vegetables (Vernieri et al., 2006).

Similarly to biopesticides, many PGRs (e.g. chlorflurenol, gibberellic acid) are excluded from MRLs (Australian Pesticides and Veterinary Medicines Authority, 2010).

Challenges and opportunities for agribiotech R&D

A previous report (Estrada-Flores, 2010) outlined the significant challenges faced by biotechnology in the context of transgenic crops in horticulture. Some of these remain valid in the context of non-GM applications. In this report we detected the following challenges:

- Lack of economies of scale due to the diversity of specialty crops and the variety of target traits in specialty crops research. Each specialty crop occupies a relatively small market niche, compared to the vast acreage of commodity crops. Just one

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23 http://www.bayercropscience.com/bayer/cropscience/cscms.nsf/id/PlaGroReg_Agro/$file/plant_growth_regulators.pdf
24 http://www.sciencedaily.com/releases/2008/08/080812100327.htm
25 WO/2009/138655. Use of strigolactones to control the growth and architecture of higher plants.

specialty crop, such as apples, may have dozens of diverse varieties, increasing research and development costs.
- Developing herbicide tolerance or pest resistance engineered into horticultural crops may be more complex than the simple gene-phenotype relationship encountered in commodity crops.
- Due to the misunderstanding between GM and non-GM agribiotech, companies carrying out R&D in the latter area will still be susceptible to government regulations in relation to research ethics and effects on human health.
- Access to government funding and venture capital is difficult. Some biotechnology companies in Australia rely on foreign partnerships to set them up.
- In a survey carried out by Research Australia (Beyond Discovery 2007), biotechnology companies identified funding, management recruitment, regulatory issues and IP protection as the main barriers for start up companies in this industry (Ellis, 2010).

However, public acceptance to GMOs is the largest hurdle faced by transgenic innovations in horticulture. These challenges are clearly illustrated by the *bt* brinjal saga: India's Genetic Engineering Approval Committee (GEAC) recommended in October 2009 to allow the commercial release of *Bt* Brinjal (eggplant). India is the second largest producer of eggplant in the world, after China. Eggplant is prone to attack by various pests and diseases that cause losses of up to 70% in commercial plantings in India. Therefore, its cultivation requires heavy applications of insecticide.

Activists protest against the release of Bt. Brinjal for commercial farming in India, in Hyderabad. Source: The Hindu Newspaper. 30 Jan 2010.

According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA), *Bt* brinjal could reduce insecticide sprays by 80% to control fruit and shoot borer, which translates into a 42% reduction in total pesticides normally used in controlling all insect-pests of eggplant. *Bt* brinjal is said to provide a 33% increase in marketable yield over the non-Bt counterparts and 45% over the national check hybrid. As a result, the 1.4 million farmers that grow brinjal were expected to reap a net benefit of US$1,539 per hectare over non-Bt varieties. This estimate included net spaying savings of US$115 per hectare. Country-wide, ISAAA states that *Bt* Brinjal could contribute to a net benefit of US$411 million per annum to vegetable producers [26].

A number of public protests were staged, calling to ban *bt* brinjal[27, 28]. In view of the negative public reception to the variety, the commercial release is now in a moratorium by

[26] http://www.isaaa.org/resources/publications/briefs/41/executivesummary/default.asp

the Indian Government, which will last until *"independent scientific studies establish, to the satisfaction of both the public and professionals, the safety of the product from the point of view of its long-term impact on human health and environment, including the rich genetic wealth existing in brinjal in our country"* as expressed by the Indian Environment Minister Jairam Ramesh[29].

In terms of capability, there are basically two types of companies currently developing agribiotech solutions:

a) Large, well-established companies that moved from supplying chemicals and seeds to the industry to also provide biotechnology-derived products and services. Examples of these companies include Monsanto, DuPont, Vilmorin, KWS, Syngenta, Dow, Ball, Sakata, Takii and Bayer Crop Science.
b) Small start-up companies that are spinoffs from university laboratories. For example, over the 20 years to 2001, 75% of biotech firms in the ACT were formed as spin-offs, 60% in SA, and 53% in Queensland (Ellis, 2010). These firms can leverage commercial investment with public funding (e.g. grants). Equivalent funding for fully commercial enterprises has not been forthcoming in the past months, which makes R&D in the latter category riskier than in start-ups.

Agribiotech applied to horticulture can draw from both types of companies. However, the challenge for advancing biotechnology focused on horticulture is the large number of varieties and the lack of economies of scale for many of these. Dr Justin Greaves (Warwick University, Nov 2007) summarises these concerns in regards to biopesticides as follows: *"...the market size is too small to provide economies of scale and encourage firms to enter. Because biopesticides are niche products with very specific applications, any one product has a smaller potential market size."*

For varieties where economies of scale make them less attractive for commercial R&D investment, public research is still an option. In Australia, CSIRO maintains the largest and most sophisticated range of glasshouses and controlled environment facilities in the Southern Hemisphere. Their work in horticulture varieties has mainly focused in citrus and macadamia [30].

Crop & Food Research in New Zealand delivers plant breeding services through their CropSeed business unit, which links plant breeders and industry – from germplasm to commercial seed production. They are working on plant breeding research focused on potato, sweet potato and vining peas[31].

[27] http://www.hindustantimes.com/Home-truths-Contentious-Bt-brinjal-GM-foods-not-on-menu/Article1-532301.aspx
[28] http://beta.thehindu.com/sci-tech/agriculture/article97617.ece
[29] http://beta.thehindu.com/news/national/article103642.ece
[30] http://www.csiro.au/science/pshv.html
[31] http://www.crop.cri.nz/home/business/breeding.php

Further, the Australian government supported the establishment of the Australian Plant Phenomics Facility[32] (APPF), which is based around automated image analysis of the phenotypic characteristics of extensive germplasm collections and large breeding, mapping and mutant populations. It will exploit recent advances in robotics, imaging and computing to enable sensitive, high throughput analyses to be made of plant growth and function. The APPF has currently two nodes:

1. The Plant Accelerator[33] is a world-class facility that was opened in the University of Adelaide in early 2010. It is one of Australia's valuable assets for research into phenomics (*i.e.* the identification of physical attributes desirable in several types of plants). The facility helps researchers to rapidly identify plant varieties that will be successful for breeding, and therefore reduce the time between the breeding of new varieties and their delivery to agricultural producers.

   Costs to use this facility are very reasonable for non-profit uses, as illustrated in the example of Table 9. It is expected that costs for profit/commercial rates would be over 2-3 times these costs, plus IP arrangements.

Table 9. Costs to use the Plant Accelerator for non-profit research. Based on 100 wheat plants in std pots, grown 2 weeks in the greenhouse and transferred into the Smarthouse for 6 weeks (imaged every second day). Grown to maturity in greenhouse.

Description	Day	Unit	Qty	Unit cost	Total AUD
Potting (1 seed per pot / not to weight), barcode labelling, watering	1	hour	3	44	132.00
Bench hire in standard evap. cooled shared greenhouse (2 benches x 2 weeks)	1-14	bench/week	4	20	80.00
Watering every second day (7 days x 2 benches)	1-14	bench	14	0.75	10.50
Transfer plants from GH to Smarthouse, loading and scanning	15	hour	4	44	176.00
Smarthouse hire for 6 weeks (100 plants x 42 days = 4200)	15-57	pot/day	4200	1.25	5,250.00
Unloading and transfer plants to shared evap. cooled greenhouse	57	hour	4	44	176.00
Bench hire in standard evap. cooled shared greenhouse (4 benches x 9 weeks)	57-120	week	36	20	720.00
Prices are based on the 2010 price list.		Total Amount (excl. GST)			6,544.50
		GST Amount			654.45
		Total Amount (incl. GST)			7,198.95

Other services (e.g. bagging flowering heads, harvesting, threshing) are charged at an hourly rate of $44.00 plus GST. Data delivery costs / extended image analysis costs may apply.

Project costing for other price categories (e.g. commercial/for-profit rates or overseas researcher rates) are available on request.

[32] http://www.plantphenomics.org.au/

[33] http://www.google.com/url?sa=t&source=web&cd=1&ved=0CBIQFjAA&url=http%3A%2F%2Fwww.plantaccelerator.org.au%2F&ei=njwYTIemHY_ZcY6wkaYM&usg=AFQjCNFF0q9EWvK0hDssiyDTkuYUUFGdEA

2. The High Resolution Plant Phenomics Centre[34] (HRPPC) is located in Canberra at CSIRO Plant Industry and the Australian National University. This Centre focuses on "deep phenotyping" (*i.e.* delving into metabolism and physiological processes within the plant) and "reverse phenomics" (*i.e.* dissecting traits to discover their mechanistic basis). Recent advances in robotics, imaging and computing are used in applying these technologies and scaling them from the single plant to the ecosystem level.

Two levels of service are provided in the HRPPC. First, projects can be housed in the facility, where screening systems can be developed using facility staff and resources then deployed in the facility and in the user's home institution. Second, users' material can be screened for specific attributes using one or more of the modules housed at CSIRO or the ANU. This node of the facility focus on flexibility from cereals to dicotyledons and woody perennials at all stages of development.

Figure 17. An installation of the High Resolution Plant Phenomics Centre in Canberra.

Pricing and access is set in three levels: 1) members, 2) non-member public sector research, and 3) commercial users. For members, costs to installations ranges from $400,000 to $1.3 million, depending on the specific installations required. For HAL members, this could be an attractive option.

Therefore, Australia has infrastructure and capability for R&D development in agribiotech. The proportion of research directed to horticulture, relative to the proportion of research focused to broadacre crops, in unknown. However, given the challenges outlined for the horticulture industry, it is expected that horticulture represents a small percentage of R&D in agribiotech.

[34] http://www.plantphenomics.org.au/HRPPC

Soilless production systems

Soilless culture is not an innovation *per se*, having been used by the Egyptians 4,000 years ago. As part of the development of soilless systems, technical developments were made to solve problems with root diseases, root zone oxygen deficiency, fertility control and increased complexity in irrigation strategy. Solutions to these problems and opportunities resulted in widespread adoption of soilless container plant production in outdoor nurseries in the 1950s and 60s. In the early 1970s, production of greenhouse crops in rockwool dramatically expanded commercially viable soilless crop production. Innovations in fertilization and irrigation resulted in adoption of fertigation technologies, where completely soluble fertilizers are dissolved in irrigation water so as to deliver to plants the nutrients they need for optimal growth.

In the wake of environmental challenges and the need of increasing food security, soilless culture is being revisited as a low-cost alternative for locations where there is a lack of fertile soils and water scarcity.

Another major driver for the development of soilless systems is the avoidance of soilborne pathogens in intensively cultivated greenhouses. The replacement of soil by inert substrates means that soilless production is virtually free of pests and diseases at the start of the operation. Further, the reuse of these substrates from crop to crop is possible, since these materials can be treated to kill any microorganisms.

In soilless cultivation it is also possible to have better control over several crucial factors, leading to greatly improved plant performance (Raviv and Lieth, 2008).

Today the largest industries in which soilless production dominates are greenhouse production of ornamentals and vegetables and outdoor container nursery production. In urban horticulture, virtually all containerized plants are grown without any field soil (Raviv and Lieth, 2008).

Supply and demand factors

The value of the Australian hydroponic vegetable and cut flower sector has been estimated at approximately $1.3-$1.8 billion per annum in farm gate prices – equivalent to around 20-25 % of the total value of vegetable and flower production[35] (Smith, 2009).

Figure 18 shows the most significant crops cultivated under cover in Australia.

[35] http://www.ahga.org.au/about/

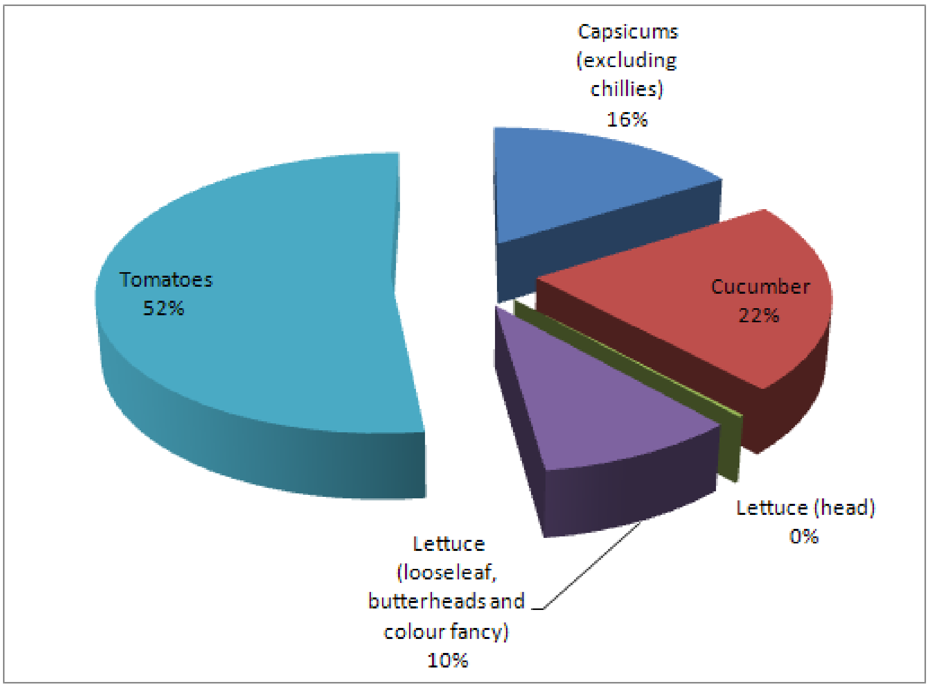

Figure 18. Proportion of vegetables grown under cover in Australia, by volume[36].

The vast majority of Australian farms operate with low to medium technology levels, lagging behind The Netherlands, US, UK and Canada, which have established best practice technologies and management systems in protected cropping systems.

The effect of levels of technology is illustrated in the comparison of the areas used for field and protected production of vegetables in the UK and Australia. These two areas are similar, as presented in Table 10. However, the UK produces 4 times more vegetables under protected cropping practices than Australia, while the latter is 1.3 times more productive in field vegetable cropping.

Table 10. Statistics of protected vegetable cropping in the UK and Australia 2007-08 (Department for Environment Food and Rural Affairs, 2009a, Department for Environment Food and Rural Affairs, 2009b, Australian Bureau of Statistics, 2008).

Country	Total area used (outdoors and protected)	Protected area (ha)	Protected production ('000 tonnes)	Field production ('000 tonnes)	Protected production yield (t/ha)	Field production yield (t/ha)
UK	118,439	680.0	247.4	2,339.7	363.8	19.87
Australia	119,610	673.6	60.1	3,177.4	89.16	26.12

Table 10 suggests that Australia is yet to reap the full benefit of protected horticulture. These benefits can be considerable, given that one hectare of protected cropping can deliver between 4 and 10 times more product than field cropping in Australia (Smith, 2009). It has

[36] ABS, 2009

also been reported that greenhouse tomato producers can achieve yields of 50 tonnes of tomatoes per mega litre of water, compared to around 8 tonnes for field producers (Riddell, 2009).

Market-wise, the conditions also favour greenhouse production: retailers have reportedly indicated to greenhouse producers that they would like to increase the proportion of greenhouse tomatoes in stores from the current level of 17% up to 50% of tomato stocks.

Innovations in soilless production systems

Hydroponics

Hydroponics is a form of soilless production, with their total water and nutrient requirements supplied by the system. Production can take place either in a greenhouse/glasshouse or outdoors.

Some common substrates used include peat, rockwool, sawdust, coir (coconut fiber dust), compost, growstones from recycled glass bottles, clay, gravel, vermiculite, perlite and others. However, several other products are entering the market. For example, the company BVB Substrates developed PBVB Sublime, a polyurethane foam with a high pore volume. In comparison to rockwool, BVB Substrates claims that cucumber production is improved between 3 and 7%, while the number of vegetables increases between 2 and 6%[37].

BVB Sublime substrate.

Another example is SteadyGROWpro soilless media, manufactured by Syndicate Sales Inc [38]. This substrate is made from primarily phenolic resin and air. The main advantage of this product is its disposability: used rockwool and urethane derived media are difficult to dispose of. SteadyGROW can be compacted or incinerated for disposal, thus occupying less space in landfill.

Hydroponics is an attractive alternative for locations where water constrains exist. Hydroponic crops produced in closed systems can produce $100 of output from as little as 600 litres of water, compared to 37,900 litres per $100 of output for non-hydroponic crops. Greenhouses can produce up to 40 tonnes per megalitre of water, compared to around 9 tonnes per megalitre of water in the field (Smith, 2009).

A recent Victorian inquiry into sustainable development of agribusiness in outer suburban Melbourne reviewed the use of hydroponics as a potential mechanism to generate food production in peri-urban areas (Outer Suburban/Interface Services and Development Committee 2010). Two recommendations of this report were: (a) that the Victorian

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37 http://www.bvb-sublime.com/BVBSublime/
38 http://colesmarketing.com/blog/tag/steadygro/

Government encourage the development of clusters of hydroponic greenhouses in those peri-urban areas which are unsuitable for soil based agriculture and have access to class A recycled water; and (b) that the Victorian Government, through DPI Victoria, support the development of technologies that enable farmers to produce their own electricity, fuels and other energy inputs. The Victorian Government is now evaluating its response to this report.

An example of an aquaponics system

Aquaponics

Aquaponics is a special form of recirculating aquaculture systems, namely a polyculture consisting of fish tanks (aquaculture) and plants that are cultivated in the same water circle (hydroponic). The primary goal of aquaponics is to reuse the nutrients released by fishes to grow crop plants.

Examples of systems developed in the past years include:

- An integrated fish and hydroponic tomato production system (Watten and Busch, 1984).
- A system suitable for urban farming, growing Tilapia and broccoli, carrots, lettuce and kale (Bender, 1984).
- A system to grow Nile tilapia and romaine lettuce (Seawright et al., 1998).
- A system to grow hybrid cat fish and garden lettuce (Sikawa and Yakupitiyage, 2010).
- An integrated system to produce fish and aubergine, tomato and cucumber (Graber and Junge, 2009).

The interest in aquaponics is on its potential for sustainable food production in a variety of scales, from small suburban systems to large commercial operations. Commercially, aquaponics has not reached its full potential. As the technology develops and is refined, it can become a more efficient and space saving method of growing fish, vegetables and herbs. By incorporating aquaponics, hydroponic growers can eliminate the cost and labour involved in mixing a fertilizer solution and commercial aquaculturists may be able to drastically reduce the amount of filtration needed in recirculating fish culture.

Indicative capital costs for commercial aquaponic systems are provided in Table 11.

Aeroponics

In aeroponic growing systems the roots of plants are suspended in a volume where emitters continually spray the roots with nutrient solution.

Table 11. Indicative capital costs (USD) for setting up an aquaponics operation. From the website: https://www.aquaponics.com.

System	Description Size of fish and raft tanks	Estimated kg of fish per year	Estimated number of lettuce per year* no lights / lights	Approximate area requirements	Cost (USD)
Farm Market 1 4-300	4 - 300 gallon fish tanks, 2 - 8' x 22' raft tanks	586	9,000 / 16,000	7.3 m x 19.5 m	$18,995
Farm Market 2 4-500	4 - 500 gallon fish tanks, 2 - 8' x 36' raft tanks	985	14,000 / 24,000	7.3 m x 22 m	$37,995
Commercial 4-800	4 - 800 gallon fish tanks, 2 - 8' x 64' raft tanks	1,571	26,000 / 48,000	9.1 m x 36.6 m	$58,095
Commercial 6-1200 Combo Clear Flow™	6-1200 gallon fish tanks 2-10' x 80' raft tanks 4-10' x 80' NFT	3,404	129,600 / 194,400	27.4 m x 39 m	$88,095

The use of aeroponics in horticulture dates from 1953, when experiments with apple trees grown outdoors with their roots in boxes showed that nutrients provided via spray successfully kept the trees in a productive state. Later, experiments with tomato plants provided similar results. Commercial systems were developed in 1973 (Weathers and Zobel, 1992).

One of the major drivers behind the development of commercial aeroponics is the need to maximise space in greenhouse horticulture: aeroponic and aero-hydroponic systems that increase the number of plants per square metre above the possibilities of hydroponics an field cultivation have been developed and patented (Weathers and Zobel, 1992). The key to all designs is the continuous feeding of nutrient solutions through gravity or spray systems.

Examples of commercial developments include the Vertical Aeroponic Planting (VAP) system. The system is a growing environment housed in an enclosure called a BIOSHELTER ®, which utilises horizontal hydroponic growing beds and vertical aeroponic growing tubes. Therefore, the greenhouses make an efficient use of space by arranging plants in a three-dimensional manner. Pumps powered by solar energy and monitored by a computer deliver nutrients to thousands of the growing tubes. Synergy International [39], the company commercialising these systems, claims that the Bioshelters have 6 to 7 times the output of conventional greenhouses. Typical products include vegetables, sprouts, berries, flowers, and specialty plants for the pharmaceutical industry.

The capital costs of a VAP system are about AUD$53.00/m^2, which is competitive with high tech greenhouses such as the Seawater Greenhouse and potentially lower than the current

[39] http://www.synergyii.com/

average costs in Australia, which range from AUD$100/m^2 to AUD$300/m^2, depending on the sophistication of the greenhouse and the level of equipment being included (Estrada-Flores, 2009b).

Challenges and opportunities for R&D in soilless systems

Soilless systems are likely to play a significant role in the world's food production system in the near future. However, greenhouses with active heating and cooling are more capital intensive production systems than field cropping. Producers will be required to incur in significant costs if switching from field to greenhouse production. The challenge for the greenhouse industry is to develop and adopt systems with less energy requirements than conventional systems. Some options were explored in Report 2.

Also, despite the fact that greenhouse production is less affected by pests than field crops, phytosanitary issues can still occur in soilless systems. Examples of these include Pythium and Fusarium root rots, Anthracnose and Botrytis blights on leaves. The incidence of these in the Australian greenhouse industry was documented in a HAL funded project (Tesoriero, 2004).

Growing crops without soil also imposes some limitations described below (Raviv et al., 2008):

- Soilless systems confine the roots into a specific, well-defined root zone. The smaller the root zone, the more intensive the production system needs to be to manage this volume. Examples of management measures include more frequent irrigation when substrates such as peat and stone wool are used; and more precises fertilization than in field cropping.
- Restricted root volume can also affect plant nutrition, for example, a decrease of calcium intake has been detected in tomato plants grown in aero-hydroponics systems. While the minimal root size to meet plant requirement for nitrogen and most nutrients is much smaller than that required for water supply, aeration and other physiological demands, the supply of phosphate and calcium may be a limiting factor.
- In container-grown plants, anatomical root changes frequently results in the accumulation of root mat on the bottom. This part of the root, which accounts for a major part of the total root biomass, may be exposed to oxygen deficiency both due to the respiration of an extensive mass of dense roots, and as a result of the existence of a perched water layer on the bottom of the container.
- Roots growing in containers are more exposed to extreme ambient temperatures than soil-grown roots. In addition, the evaporation of water from the root zone is high, due to the typically high surface-to-depth ratio, as compared to soil-grown plants. Evaporation can be important in outdoor nurseries and in newly planted media. Anaerobic processes may occur within the root tissue, significantly lowering its water and nutrient uptake and its growth rate. High temperature may negatively affect the activity of nitrifying bacteria which could lead to toxic ammonium levels.

- In ground field production, there is frequently variability in soil characteristics within the field. Plants will generally grow and yield differently in the various parts of the field. In soilless production, standard best-management practices will lead to have the same growth. Therefore, in soilless production a uniform management strategy for a particular crop is ideal, while in field production, better productivity can be achieved by customizing irrigation and fertilization, depending on the variations in soil within the field. With innovations in precision agriculture, it can be expected that such optimization will be feasible, yet currently this type of optimization is not yet feasible in field production. With soilless production, on the other hand, such customized optimization is possible although it is questionable how economically feasible it is.

With 50.5% or 3.5 billion of the world's population living in cities in 2010 and urban populations growing, often at the expense of rural areas, the global population as a whole has become more urban and less rural (United Nations 2010). Land use policies and economics are not helping in generating food production belts around cities, as these generally encourage the use of peri-urban land for urban development (Jewell, 2008).

In terms of food distribution, this means that the transportation necessary to deliver primary production to manufacturers, retailers and consumers is also increasing, as less people live near production areas and more shops are located in population centres (Marquez et al., 2010).

The integration of horticultural production in urban settings is one potential way to improve urban food security, while also decreasing the impact of food transport. Examples of such integration include the concept of "vertical farm"[40], which consists on the indoor production of products typically grown in glasshouse production, such as herbs, strawberries, tomatoes, peppers and cucumbers. City-based glasshouses could be run in some large roof areas, for example, warehouses and shopping centres. Examples of innovative designs to integrate horticultural production in cities are provided elsewhere (Estrada-Flores and Larsen, 2010).

An example of intensive crop growing for cities: the VertiCrop systems for lettuce ((http://www.valcent.net)

Research on soilless systems and protected horticulture is needed, particularly in regards to energy efficiency. Although one hectare of glasshouse production can deliver between 4 and 10 times more product than field cropping in Australia (Smith, 2009), it does so by consuming about 900 times more energy than the same area in field cropping (Estrada-Flores, 2009b). This significant expenditure is due to the need of constant ventilation, temperature, humidity, irrigation and carbon dioxide for the optimum growth of crops.

[40] http://www.verticalfarm.com/

The amalgamation of new technologies in the field of climate control, sensors, vision technology and automation can provide breakthroughs in protected horticulture, as has been demonstrated by work at PlantLab[41], a Dutch company that proved and then patented the feasibility of cultivation in completely conditioned spaces without daylight in 2006. PlantLab's home base is the new Centre for Growing Concepts at the University of Applied Sciences HAS in Den Bosch. This research centre developed by PlantLab includes 8 climate cells in which plant research can be carried out under 56 different environmental factor combinations simultaneously.

Agricultural machinery for production and harvesting

A previous report (Estrada-Flores, 2009a) provided an overview of mechanical and robotic harvesting technologies, in the context of supply chain innovations. Additionally, a current HAL project –HG09044 "Mechanisation, Automation, Robotics and Remote Sensing (MARRS) in Australian horticulture", led by Mr Russel Rankin– is investigating alternatives to develop the platform for HAL members.

Supply and demand factors

The agricultural machinery industry in Australia encompasses 847 businesses that cumulatively produced $1.4 billion in revenues during 2009 (Connell, 2009).

Australian manufacturers ceased producing tractors in Australia in the late 1980s. Firms in the industry lacked the economies of scale, access to technology and low cost labour markets necessary to compete on the global stage. As a consequence, the use of imported equipment (manufactured mostly in the US and Europe) in Australian agriculture is estimated to be as high as 85% of the total equipment used (Wilkie, 2008). In particular, the imported tractor segment is a highly competitive sector, with approximately 40 different companies offering an estimated 700 models (Wilkie, 2008).

Australian manufacturers are small, not exports focussed, and prefer to concentrate on lower-value products developed to suit arid Australian conditions and niche markets. The industry's developments have therefore focused on tillage technology and seeding equipment, which represent about 70% of the industry's revenue (Connell, 2009).

Some of the major players in agricultural machinery in Australia are Victa, Honda Motorcycle and Power Equipment, John Shearer Holdings Ltd, Silvan Australia, AF Gason Pty Ltd, Elders, UR Mildura Pty Ltd, Goldacres, John Berends, Grizzly Engineering Pty Ltd, Challenges Implements and Howard Australia (Connell, 2009).

Worldwide, the most exciting developments in agricultural machinery relate to the introduction of geospatial technologies and smart sensors. These technologies were

[41] http://www.plantlab.nl

reviewed in Report 1 (Estrada-Flores, 2009a). This trend is reflected in the best prospects for sales in this area, which include (Wilkie, 2008):

- Technology that allows remote access to or can control agricultural functions.
- Equipment that automates agricultural tasks that are currently manual.
- Water management devices or tools for agriculturists, particularly self propelled sprayers.
- Precision farming and farm management tools.
- Specialized machinery parts.

In terms of farm purchase behaviour, it follows an irregular pattern. As in many other industries, larger equipment purchases decrease in lean years, with more purchases made following a boom year. Like farmers, machinery and equipment dealers are affected by prevailing weather patterns and subsequent crop yields.

Australian agricultural producers prefer to see and test new equipment before buying it. There is a significant amount of peer consultation in the buying decision. This has led to a proliferation of farm exhibitions and trade shows, which provide the opportunities to both network and consult with other farmers, and see the equipment (Wilkie, 2008).

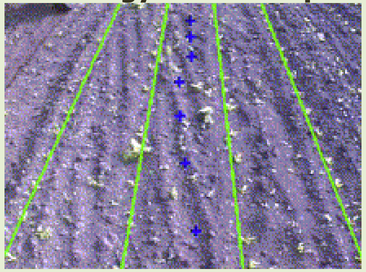
Given the spread of the agricultural industry across Australia, product distribution and support can be a complex issue – and one of the primary purchasing concerns. Several large wholesaling groups covering a range of smaller agricultural equipment and chemicals have evolved to address the distribution issue (Wilkie, 2008).

Larger equipment such as tractors, harvesters and tillage equipment are brokered by individual equipment dealers, who often cover several brands. Regional centres might have 1 or 2 equipment dealers, having more dealers in larger centres. Equipment dealers can be reluctant to upset their existing suppliers by introducing competitor products, given the level of co-branding and marketing support they receive from larger suppliers (Wilkie, 2008).

Innovations in agricultural machinery

Table 12 summarises some innovations in agricultural machinery made in recent years.

Table 12. Recent developments in agricultural machinery with application to vegetables.

Technology	Use	Reference
Precision guidance technology in row crops  	With the withdrawal of a number of agrochemicals formerly used to control weeds in horticultural row crops, there has been renewed interest in mechanical weed control. However, operating inter-row cultivation equipment at high work rates is a demanding task, because of the need to maintain very accurate alignment. Computer vision can be used to match the row to an electronic template, corresponding to the known planting pattern. A machine vision guidance has been used to address the problem of mechanically removing weeds within rows of transplanted vegetables and salads. The "Robocrop" machine was based on a commercially available steerage hoe equipped with conventional inter-row cultivation blades. A vision system detected the phase of approaching plants and that information was combined with measured disc rotation to calculate a phase error between the next plant and disc cut-out. This error was corrected by advancing or retarding the hydraulic drive, enabling synchronisation of the mechanism, even in the presence of crop spacing variability. Field trials in transplanted cabbage indicated that under normal commercial growing conditions crop damage levels were low, with weed reductions in the range 62–87% measured within a 240 mm radius zone around crop plants. During a thinning trial in lettuce, it took the hand crew 11.6 hours per acre to complete the task while the RoboCrop took 4.2 hours per acre. After thinning, plant populations were 28,000 per acre for the hand crew and 31,000 plants per acre for the RoboCrop thinned area.	(Wrest Park History, 2009, Tillett et al., 2008) (Inman, 2010) http://www.solexcorp.com/
Band steaming for intra-row weed control 	A new prototype of an integrated machinery system for weeding[42], which involves band steaming for intra-row weed control, has been developed. The soil is thermally treated in a narrow bandwidth of 8 cm around the crop rows at a depth of 5 cm prior to crop establishment in order to reduce weed seedling emergence. The subsequent sowing is carried out automatically following a track pre-set by the bandsteamer. The control of inter-row weeds is carried out by means of traditional hoeing. The system is intended to increase the yield of organically grown row crops such as outdoor vegetables, maize and sugar/fodder beet.	(Sørensen et al., 2005)
Harvesting rig for asparagus	Cobrey Farms (UK) teamed up with Haygrove Ltd to develop a harvesting rig that is suitable for	http://www.ha

[42] http://www.darcof.dk/enews/sep04/steam.html

grow in plasticulture. 	use on asparagus grown under plastic. The motivation was high cost of harvesting polythene-covered asparagus by hand. The Haygrove rig costs around £70,000 (AUD$120,465), but it is capable of reducing harvest costs by 28p (AUD$0.48) per kilogram. If harvesting 100 tonnes of asparagus each year, it can repay the investment within three years. It also reduces the number of harvest workers needed.	ygrove.co.uk/ http://www.hortweek.com/news/1001333/Technological-innovations-harvesting/
Field transplanter 	Williames Pty Ltd in Warragul (VIC) developed an automatic field transplanter. The machine automatically selects seedlings from a tray, transfers it to the drop tube and plants it in the ground. One person can plant up to 16 rows and each head plants up to 2 plants per second. It transplants large variety of plant types and plug sizes.	http://www.williames.com/
Self-propelled harvester 	Vegetable Harvesting Systems developed a self-propelled harvester that can travel up to 32 km/hr on the road or 60 m/hr in field mode. It has selectable two-wheeled drive and two and four-wheeled steer and can be up to 9 m long and up to 6 m wide. Any type of harvesting unit can be fitted to the front.	http://www.vhsharvesting.co.uk
Precision pneumatic seeder 	Sfoggia Agriculture Division developed CALIBRA, a precision pneumatic seeder for greenhouses and field crops. The CALIBRA seeding elements can each seed one, two and even three rows per seeding shoe element (single or two rows for the "TWIN" model, (three rows for the "TRIS" model). The CALIBRA is mounted with two blower units, one for pressure and the other for vacuum, thus maximising efficiency and avoiding humidity build up in the seeder body. CALIBRA can seed chicory, lettuce, celery, tomato, peppers, eggplant, turnip, parsley, fennel, onion, cabbage, spinach, beet, bean, and other similar seeds.	http://www.sfoggia.com/
Seeder with flexibility to be	The Clean Seeder by Jang Automation Co., Ltd. of South Korea, can plant virtually any size seed.	http://www.m

used with several types of crops 	A 3-row push style seeder is reported to cost US$980. A roll-type, tractor mounted 15-row seeder costs up to US$11,000. Each row of the latter model can be divided to plant a total of 30 rows, 2" apart.	echanicaltransplanter.com
Cabbage harvester 	Univerco manufactures a cabbage harvester that works with a crew of 6 workers to pick up 200 to 250 tons per day. A cabbage harvester costs between US$300,000 and $400,000. A small, seasonal grower would not be able to justify this cost. However, sharing the costs with growers harvesting other crops in different months could be an option.	http://www.univerco.net/
Mechanical harvesters for leafy greens 	Ramsay Highlander manufactures the Headrazor Mechanical Harvester, designed to harvest romaine, green leaf, and a version for iceberg. While a typical romaine harvest requires 40 people, the Headrazor can reduce the headcount to 15. The machinery costs approximately $450,000. Ramsay Highlander also introduced a spring mix/baby leaf harvester, using band saw technology (also used on the Headrazor) to cut the leaves. Ramsay also has a water-jet harvester capable of harvesting 5,400 kg of Romaine per hour into totes, and up to 10,000 kg per hour in a bulk loading version. The water jet harvester has a sanitary cutting method and can negotiate uneven beds. It consumes less than 6 litres of water per minute when harvesting 6 seed lines and has a 1,325 L reservoir, with quick fill attachments.	http://www.ramsayhighlander.com/
Robotic Automated Pest Detector	Dr Jeff Drake, an USDA engineer, has developed a Robotic Automated Pest ID (RAPID) system which identifies and sorts insects through robotics, image recognition and analysis technologies. This system can identify insects at the genus level, with accuracies approaching 95%. Small operational changes to the system can bring this accuracy to almost 100% and increase the possibility of identifying down to the species level in the future. The image recognition component is versatile enough to incorporate new or varied identification characteristics, depending on the species of interest. Some work is still required to fully automate the	http://www.crcplantbiosecurity.com.au/publications/npb1298

	sample delivery system, which will depend largely on the required application.	
Unmanned aerial vehicle tehcnology 	Unmanned aerial vehicle technology is being considered for field spore sampling. This technology, which is being developed by the CRC Plant Biosecurity, would open the possibilities of covering extensive areas for exotic plant pathogen surveillance. This tool will greatly enhance the ability to detect new incursions of fungal pathogens and to enable more accurate delimiting of distribution. The technology will allow for earlier detection of pathogen incursions in difficult areas and provide efficient and effective airborne surveillance. The complete integration of the modified spore trap onto land and aerial vehicles is expected to be completed and tested by May 2010, with a final report and recommendations for commercialisation by June 2010.	http://www.crcplantbiosecurity.com.au/publications/npb1276

Challenges and opportunities in R&D for agricultural machinery

It is widely recognised that efficient mechanisation is a major factor underlying the high productivity and low cost of some Australian crop production systems. Efficiency has generally been associated with greater work rates, achieved by using equipment of greater power and weight (Tullberg et al., 2007, Horticulture Australia Limited, 2008). However, it would be naive to assume that all types of cropping operations are reaping the benefits of mechanisation.

If we analyse global literature on precision agriculture, Australia is often cited as an early adopter (Swinton and Lowenberg-DeBoer, 2001, Fountas et al., 2005). A closer look indicates that broadacre systems for grains, oilseeds, sorghum and others are the true early adopters of precision agriculture in crop production (Estrada-Flores, 2009a). Furthermore, the benefits of precision agriculture are likely to benefit broadacre crops the most (ACIL Tasman, 2008b).

The usage of enabling technologies for mechanisation (e.g. computer and internet technologies) remains low in agriculture as a whole (Estrada-Flores, 2009a). In 2007-08, only 63% and 69% of fruit and vegetable farms in Australia were computer and internet enabled, respectively. This author believes that increasing the level of uptake of basic computer technologies is a pre-requisite for successful uptake of other ICT-based innovation, such as precision agriculture, mechanical and robotic harvesting and others.

Another barrier to innovation is the financial ability of farms to access innovative mechanical systems. Figure 19 shows the estimated value of agricultural operations of Australian vegetable growers in 2007-08 (Australian Bureau of Statistics, 2009). Nearly 60% of these organisations are below $150,000 per year. For the majority of these operators, purchasing a mechanical harvester costing between $100,000 and $450,000 (as per information in Table 12), which remains idle for the majority of the year, would be an unwise decision. Collaborative schemes whereby mechanical harvesters are purchased through associations or cooperatives, so that the machinery cost and use is shared among participants, could be an alternative for small and medium size farm operations.

Australian-based innovation in agricultural machinery is in a state of decline and most innovations are occurring overseas. While importing agricultural equipment saves greatly in R&D investment, there may be trade-offs between these savings and the productivity achieved with machinery developed for conditions not prevalent in Australia. This author believes that Australian innovation has an important role in light of the unique challenges that the country faces, namely an on-going severe drought, decreasing availability of farm labour supply, increased competition from low labour cost countries, salinity and soil acidity, political and social ambivalence toward genetically modified crops, strict quarantine regulations and ongoing pressure to farm and distribute foods in more sustainable ways (Wilkie, 2008).

Design of farm machinery, equipment and management tools greatly depends on technical factors (*e.g.* system and process quality control) and socio-economic factors (*e.g.* trade-offs between investment and benefits, labour costs, receptivity to innovation) to optimise uptake, costs, inputs, quality and yield (Jongenbreur and Speelman, 1997). Therefore, approaches to the development of new machinery for horticulture cannot be one-dimensional. Capabilities in ecology, ergonomics, sociology and biological sciences exist in CSIRO, universities and commercial enterprises. However, the integration of these disciplines is the focus of biosystems engineering, which is an academic discipline that is underdeveloped in Australia, in comparison to USA and Europe. There is a consultancy firm that is using this approach to develop novel harvesting concepts for forestry and broadacre crops[43].

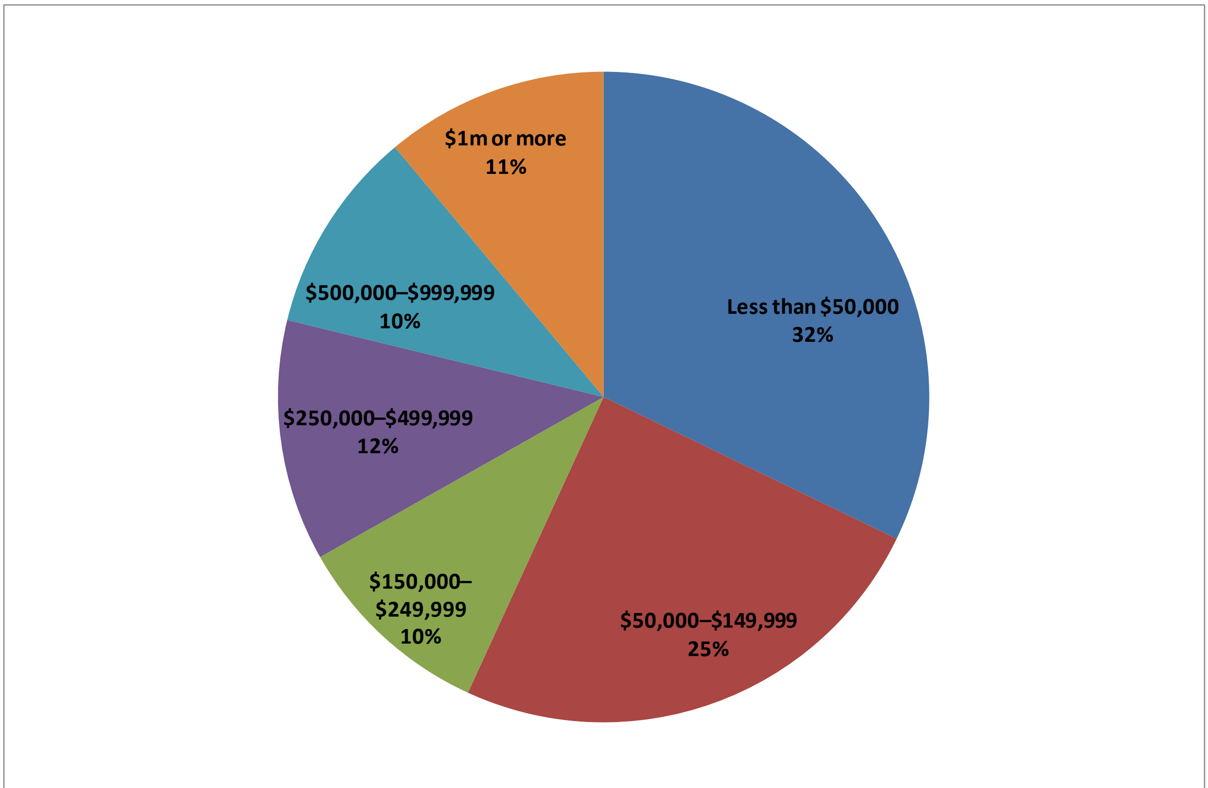


Figure 19. Proportion of vegetable growers as per the estimated value of agricultural operations in the period 2007-08.

[43] http://www.biosystems.com.au

HAL-Funded Projects in Technologies for Production and Harvesting

To detect the major focus of investment in HAL projects, a list of the titles of all vegetable funded projects[44] in novel processing technologies was analysed. Titles of projects and start dates were extracted from the HAL database by performing a keyword search that reflected production and harvesting technologies, *i.e.* project titles with concepts such as:

-Irrigation
-Harvest or Harvesting
-Hydroponics
-Glasshouse or protected cropping
-Organic
-Genetically modified crops[45]
-Precision agriculture[46]
-Mechanical/robotic harvesting[45]

This search led to a sub-sample of 214 projects funded between 1988 and 2009. The analysis considered both fruit and vegetable types of projects, as it is believed that diffusion of technological developments is common between these areas, particularly in the context of HAL's activities.

Figure 20 shows that HAL projects follow a bi-logistics behaviour, with the earliest curve representing pre-2004 projects with a wide diversity of themes, including chemical thinning agents, chemical residue analyses and biological replacements for pesticides. In 2004, a large number of projects focused on the development of minor chemical use – an across industry project that assisted growers to be compliant with MRLs and also progressive in terms of up-to-date practices. The 2nd wave of technology entered maturity in 2006 and the peak number of HAL projects on these areas is expected to occur in 2024.

From all the platforms investigated, production and harvesting seem to be the longest running and the topics that are likely to continue to be supported in the future, under current funding strategies.

Figure 21 shows the main themes developed in production and harvesting. Almost half of the projects in this platform relate to crop control and plant health issues. The second theme in importance is irrigation. Very few projects are being developed for protected cropping.

This analysis is based on the number of projects, as distinct to the financial investment made on the area. HAL has an average spend per project of around $72,000 per year (Horticulture Australia Limited, 2008), which is relatively small. If future HAL strategies switch to fund fewer (but larger) projects in this and other areas, future analyses should be performed in terms of investment.

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[44] This list was provided by Phillippa Lorimer, HAL, on June 2010.
[45] Using data from a previous search by Helen Sargent, Oct 2009.
[46] From a previous search conducted by Helen Sargent in June 2009.

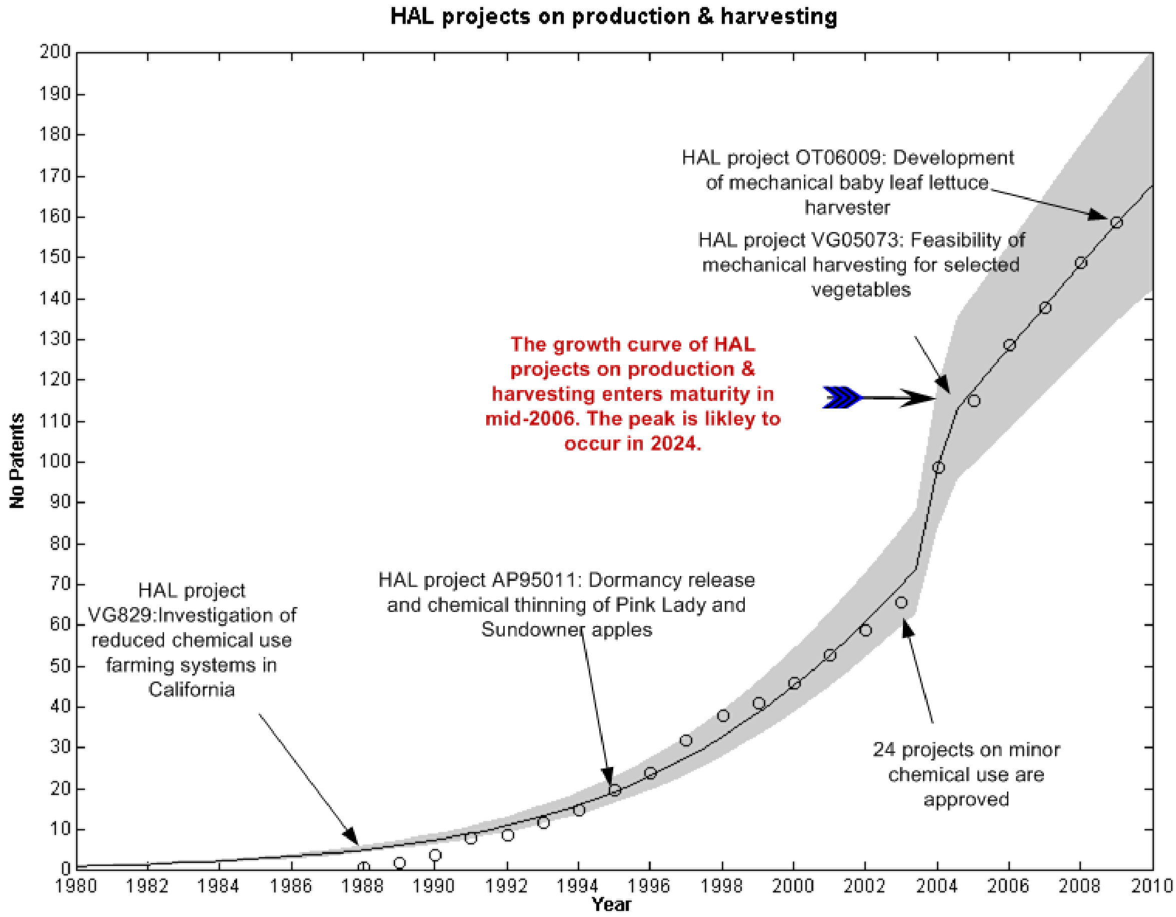

Figure 20. Historical cumulative number of projects developed with HAL funding in emerging technologies for production and harvesting of fruit and vegetables.

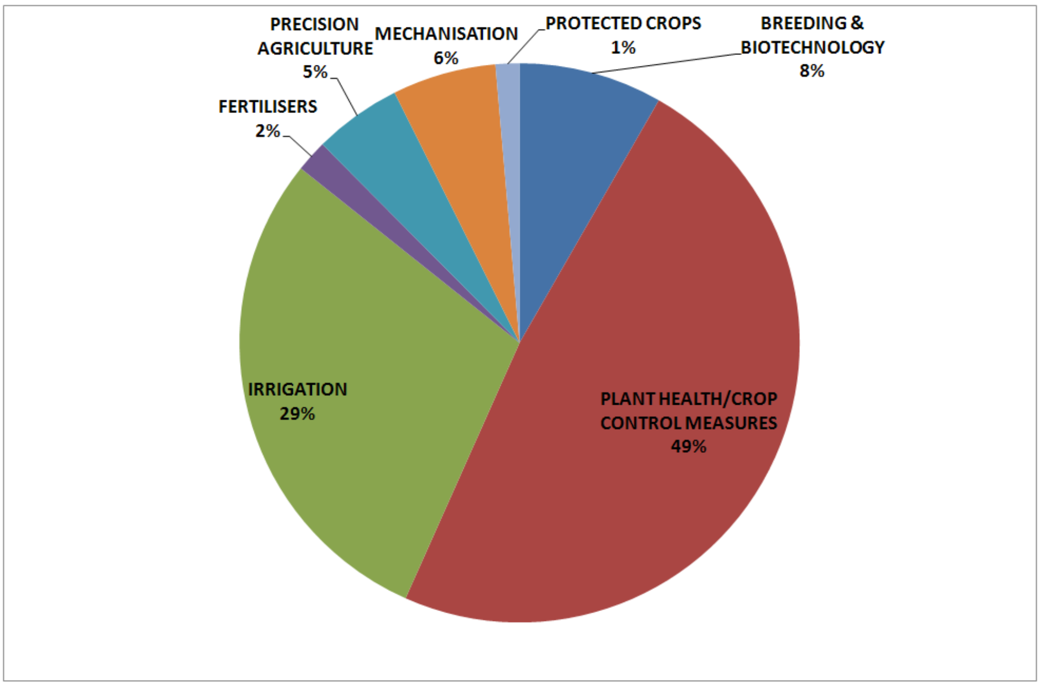

Figure 21. Percentage contribution of main themes on production & harvesting R&D areas in 217 HAL funded projects.

Implications and Recommendations

Figure 22 shows that production and harvesting are only second to environmental technologies in terms of the number of projects developed by HAL since 1998. However, some projects were counted in more than one category. For example, minor chemical use relates to mitigation of climate change impacts, biosecurity and food safety, thus fitting in three platforms (FSQ, ET and PHAR in Figure 22). Irrigation was also analysed in the ET platform. Mechanisation was analysed in supply chain technologies and in this report (PHAR and SCL).

Despite this overlap, it is evident that a large proportion of R&D investment administered by HAL on behalf of growers has been dedicated to crop control aspects and irrigation.

It is worthwhile to compare the profile of Figure 22 with the expected investment outlined by Future Focus (Horticulture Australia Limited, 2008), as presented in Table 12.

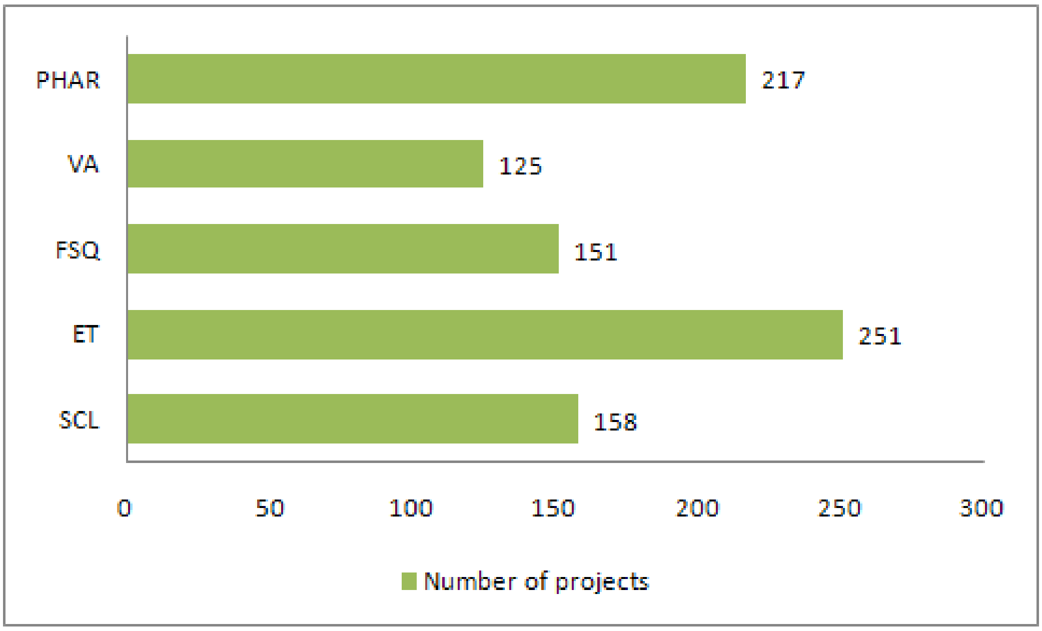

Figure 22. Comparison of projects developed in the five emerging technology areas investigated in project VG08087. Codes: SCL= supply chain & logistics; ET= environmental technologies; FSQ= food quality & safety; VA= value addition; PHAR= production and harvesting.

Table 12. Indicative reliance of sub-program on capabilities: relative importance. Source: Future Focus, 2008.

Programs:	*Building consumer demand*					
	What consumers want			*Product to consumers efficiently*		
Sub-programs:	*Novel products*	*Consumer satisfaction*	*Clean & green*	*Communi-cation & promotion*	*Commercial/ marketing platforms*	*Productivity*
Engines/capabilities	Shares	Shares	Shares	Shares	Shares	Shares
R&D engine	**0.85**	**0.88**	**0.87**	**0.75**	**0.74**	**0.68**
– Taste/perception sciences	0.19	0.21	0.17	0.40	0.19	0.05
– Breeding and genetics	0.27	0.29	0.14	0.05	0.19	0.05
– Cool chain/quality management	0.24	0.28	0.05	0.05	0.20	0.10
– Value adding/ processing	0.06	0.07	0.05	0.05	0.04	0.05
– Farming systems	0.04	0.03	0.22	0.10	0.09	0.20
– Water productivity			0.11	0.05		0.10
– Pests/biosecurity	0.04		0.13	0.05	0.04	0.13
Information engine	**0.10**	**0.07**	**0.06**	**0.20**	**0.19**	**0.25**
– Data – techno/economic	0.05	0.05	0.05	0.10	0.11	0.05
– Lessons	0.05	0.02	0.01	0.10	0.05	0.15
– Benchmarking					0.02	0.05
Policy engine			0.02		0.02	0.02
Leadership drive train	0.05	0.05	0.05	0.05	0.05	0.05
Total	1.00	1.00	1.00	1.00	1.00	1.00

Source: *HI_Link* model, TheCIE.

In Table 12, commercial/marketing platforms and novel products are presented as the main engines of growth, with potential payoffs of $590 and $500 million respectively by 2020. Key R&D platforms recommended are consumer sciences, breeding and genetics and cold chain management and QA. Currently, these same platforms receive little funding from HAL.

In contrast, farming systems, water productivity and pest/biosecurity receive lower relative importance rankings in Table 12. Yet, these are the areas that have received more support from HAL in the past 20-30 years. On the basis of the analyses conducted in the five reports completed in this project, *Future Focus* proposes a radical change in the funding directions of HAL for the vegetable industry.

Recommendations for future R&D funding

a) *Revisiting R&D priorities in Integrated Pest Management, Minor Chemical Use and Irrigation as presented in Future Focus.* These two areas of investment are highly relevant to the vegetable industry. In this report, we reviewed current challenges, including the review of commonly used chemical control agents by APVMA and the projected costs of biosecurity to the industry in 2020. These costs were not considered in the HI_LINK model used to develop the *Future Focus* platforms, which seems to have used only the costs of reducing chemicals. As shown in Tables 2 to 6, major costs are likely to arise from revenue losses due to pest invasion.

A risk analysis of the change in investment strategies is therefore recommended, accounting for both direct and indirect costs to the industry if switching investment away from crop control and irrigation. Risk analysis should concentrate on the comparison of current and projected scenarios, taking into account the damage potential of under-investing in these areas.

Having said this, the focus of current investment in both crop control and irrigation needs to be reconsidered. Crop control investment seems to be directed to "fire fighting" measures such as training and management, driven by increasing regulatory pressures in chemical pesticides. The majority of projects in irrigation research seem to focus on improving the efficiency of this operation in a range of crops. Projects on truly innovative technologies in these areas, *e.g.* those linked to precision agriculture and biotechnology, are less common.

A balance between projects responding to current pressing needs and future needs in the vegetable industry needs to be achieved in R&D funding. To do so, it is recommended that for each of the portfolios and R&D "engines" in *Future Focus*, an investment strategy that ramps up funding for the commercial/marketing platforms and novel products areas in the next 5 years is outlined.

b) *Collaborative funding.* Given that the R&D platforms with priority investment are consumer sciences, breeding, genetics, cold chain management and QA, other sources of investment to cover crop control and irrigation must be found. In this context, funding from organisations such as RIRDC, DAFF,DPI and state agencies could be discussed.

Furthermore, HAL could look for opportunities to leverage R&D investment with organisations that are working in precision agriculture for broadacre crops. Some technologies in this area could be transferable to horticulture with some adaptations. However, innovations in biotechnology are less transferable. The development of this area relies on HAL funding and potential collaborations with organisations such as CSIRO and the Australian Plant Phenomics Facility.

c) *Integration with strategies developed for protected cropping.* It has been emphasized that protected cropping presents significant opportunities in the production for vegetables, in view of environmental impacts, land use and population challenges. Of the approximately 1,500 protected cropping growers nationally, about 95% use low and medium levels of technology (Horticulture Australia Limited, 2007). The potential for growth in this industry is significant.

However, there is no specific distinction of vegetable levies paid on many crops grown used protected cropping systems. Therefore, industry priorities in the VegVision 2020 strategic plan do not fully encompass priorities for the protected cropping industry. Field and protected production are both needed to develop a secure supply chain of Australian-grown vegetables and to face competition from imports.

Research on energy efficiency in greenhouse production and investment in innovative aquaponic and hydroponic systems would be of benefit to the industry. Also, innovative urban farming systems and the positive impact of growing vegetables near or in urban centres should be investigated.

d) *Biosystems engineering and ICT.* Australian-based innovation in agricultural machinery is in a state of decline and most innovations are occurring overseas. While importing agricultural equipment saves greatly in R&D investment, the trade-offs between these savings and the productivity achieved with machinery developed for conditions not prevalent in Australia need to be better understood. The need of a biosystems engineering approach to develop sophisticated agricultural machinery adapted to Australian conditions was highlighted. This topic also links to the need of developing ICT uptake at farm level. Developing communication and awareness about the needs of the modern horticultural industry in universities could positively influence the development of curricula that addresses these gaps.

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APPENDIX A. Economic annual impacts of vertebrate pests in Australian agricultural and horticultural industries ($m).

Industry	Pest			Total
	Foxes, rabbits, wild dogs, feral pigs[1]	Birds[2]	Mice[2]	
Beef	187.7			187.7
Lamb	20.0			20.0
Wool	71.3			71.3
Grains	5.9		22.8	28.7
Nuts		48.9		48.9
Pome fruit		85.0		85.0
Stone fruit		58.4		58.4
Wine /grapes		120.8		120.8
Totals	**284.9**	**313.1**	**22.8**	**620.8**

[1] These are estimates of net losses as the change in economic surplus.
[2] These are estimates of total losses as the change in gross revenue.