SOME FUTURE TRENDS FOR THE PRODUCTION OF VEGETABLES IN AUSTRALIA

A report for

by **TIMOTHY HARSLETT**

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Tim is a 4th generation farmer and has been full time on the family farm for a little over 6 years. He completed a B Agriculture Science – Plant/Soil with Honours Class IIB.

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Foreword

Realising external factors were affecting the future of a fourth generation vegetable business, Tim Harslett undertook a Nuffield Farming Scholarship to study methods to combat these changes. To those who know Tim, this was no surprise as he is always looking at alternative methods to improve the way of doing things.

Tim travelled the world primarily to study mechanisation in the vegetable industry as a method to help alleviate a major issue affecting his business, quality and availability of labour. Reading this report Tim outlines that mechanisation isn't as simple as buying a new machine. A whole systems approach is needed to make mechanisation work for vegetable production.

Tim outlines what factors are driving labour issues not only in Australia but also in other countries, and gives examples of what these countries are doing to combat their labour issues.

If you're planning on being in the Australian vegetable business take note of the recommendations that Tim makes. Not only does he outline why mechanisation may or may not work, he has documented some other global drivers that are likely to filter into the Australian vegetable industry sooner rather than later, particularly the use of chemicals.

Learnings from Tim's participation in the Nuffield Scholarship can already be seen in Tim's family enterprise and should continue in the future.

Read this report and you will realise that, "*Good farmers don't make excuses; they find ways to overcome challenges*."

Clinton McGrath
Industry Development Officer
Queensland Department of Primary Industries and Fisheries.

Acknowledgments

Firstly, I would like to thank the family members involved with Harslett Farm and the staff we employ. I was absent from the farm for a total of 20 weeks in a 12 month period for scholarship related travels. Each person involved in the farm in some way had to cover for my absence.

Nuffield Australia is owed many thanks for giving me the opportunity to complete this wonderful travel and education experience. The knowledge and personal development gained from the Nuffield experience will be invaluable.

My sponsors, Horticulture Australia, in partnership with Ausveg, have enabled this opportunity. I am proud to be the inaugural recipient of the scholarship sponsored by these organisations. Hopefully, they will reap the benefits of this relationship with Nuffield to warrant their continued support.

Duchy College and the Worshipful Company of Farmers in the United Kingdom need to be acknowledged for allowing me to attend their annual “Challenge of Rural Leadership” course in 2007. They make a position available for one Australian Nuffield Scholar each year.

Finally there are countless people to thank for making my travels an educational and rewarding experience in every country I visited. There were numerous people in Australia, New Zealand, Ireland, France, USA, China, the Philippines, Canada, England, Scotland, The Netherlands, Denmark and Sweden who willingly gave their time and knowledge to enhance my experience.

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Executive Summary

- Labour availability and rising costs are going to become increasingly problematic for vegetable producers. Employers need to be looking for the means to overcome this challenge.
- Mechanisation and robotics are the best option for decreasing the reliance on human input.
- Machines and robots work optimally when the crop and field conditions are of a high average quality with minimal standard deviation. This means that a move to mechanisation and robotics will inevitably lead to a higher standard of agronomic practices and a better quality crop that will give a higher return.
- Other less tangible benefits of mechanisation include: machines usually work at a faster and more constant speed than humans, the remaining labour input is usually a more desirable job, reduced labour requirement means less stress for management and/or potential for expansion without increasing labour capital.
- There are examples of just about all leafy vegetable crops being harvested with machines around the world. There are various types of machines, but they all involve a cutting and lifting mechanism.
- For a farmer to embrace mechanisation and robotics they must embrace the concept that "*Good farmers don't look for excuses; they find ways to overcome challenges.*"
- Social and environmental concerns are going to restrict the use of chemicals for control of weeds and diseases in vegetable production/agriculture. Farmers need to look at alternative methods of weed and disease control.
- There are a wide variety of methods to reduce reliance, improve effectiveness or eliminate the use of chemicals. Each method needs to be evaluated on a farm to farm basis. In a majority of cases farmers should be looking at alternative control options regardless of social and environmental pressures being put on chemical use.

ABSTRACT

Labour availability and cost are a serious issue for the vegetable industry. The main topic of my Nuffield Scholarship was to look into developments in mechanisation of vegetable growing and harvesting processes as a means of reducing reliance on the need for labour.

The issues related to labour are similar in all parts of the developed world. It came to my attention that there are numerous mechanisation techniques that Australian farmers could and should be adopting, as well as developments in robotics or more autonomous machines which are being introduced to the industry.

Justifying the capital expense to introduce mechanisation on a farm is always going to be a barrier to technology uptake. The most obvious justification is the potential saving in the cost of labour. There are other, not so quantifiable reasons to make the investment. Labour is increasingly difficult to obtain regardless of the cost. Switching to machines also motivates farmers to improve their growing practices and decrease the standard deviation of the crop evenness, which will result in a higher quality crop.

Farmers who see the opportunity and want the challenge of implementing mechanisation will ultimately reap the rewards for their investment.

My secondary topic for research involved looking into different methods of weed and disease control to complement, or as an alternative to conventional use of pesticides. Rightly or wrongly society is going to demand that farmers reduce their reliance on chemical controls because of social perception and environmental reasons. There are many different techniques that can be utilized to complement or replace pesticide use. Each farmer needs to evaluate how effectively and feasibly a range of different control methods could be integrated to suit their system.

1. INTRODUCTION

In taking on the challenge and opportunity to complete a Nuffield Farming Scholarship I chose two main topics to research. 1. “The Role of Mechanisation in Vegetables”. 2. “Alternative Methods of Weed and Disease Control”. I deliberately chose to focus both topics on vegetable production as opposed to post-harvest and the supply chain. I consider my expertise as being in growing crops rather than in post-harvest processes. There are far greater opportunities to increase profitability by improving growing practices than by trying to become heavily involved in marketing.

Underscoring the main study topic, “The Role of Mechanisation in Vegetables”, are the problems based around farm labour. The cost of labour is ever increasing and the ability to find willing and competent workers is becoming more difficult. Along with decreasing the labour requirements, mechanisation can potentially make a vegetable farming enterprise more efficient and productive.

Consequently, I have posed the following questions: What is causing labour supply issues? How are other countries confronting similar problems? What current mechanisation technologies are being implemented around the world? What technologies are likely to become available in the foreseeable future? I also want to highlight some of the economic justifications for mechanisation investment. A key objective has been to relate what relevance these technologies have to the Australian vegetable industry.

Within the topic: “Alternative methods of weed control and disease control”, I have chosen to look at techniques that should be considered as replacement or complementary to conventional use of herbicides and fungicides. Integrated pest management (IPM) has become a well known approach to controlling insect pest populations. It has and is being implemented in many agricultural systems around the world to varying degrees. My intention was to find out what practices exist that may be able to be integrated into present weed and disease management strategies so that the principles of integrated weed management and integrated disease management may become widely used practices.

SECTION A – MECHANISATION POSSIBILITIES IN THE VEGETABLE INDUSTRY

2. THE LABOUR ISSUES

2.1 HORTICULTURAL LABOUR IN THE CONTEXT OF AGRICULTURE

Before starting this chapter there is a need to clarify the difference between agriculture, horticulture and vegetable production. Horticulture refers to all fruit, vegetable, nursery, flower and turf production. It is part of the agriculture industry. Vegetable production is a sector of the horticulture industry. There are instances in the report where it is difficult to differentiate the sub sectors.

Horticulture in Australia is worth some $7 billion per year (www.horticulture.com.au), of which $3.2 billion is attributable to vegetables. Before the recent upsurge in grain prices, horticulture ranked second to beef in terms of agricultural value to the economy.

The horticulture industry in Australia employs around 100 000 people or approximately 20% of people employed in agriculture. It is not possible to calculate exactly how many are employed in vegetables because many horticultural enterprises grow a combination of fruit and vegetables. As of 2005, there were 4090 vegetable enterprises in Australia. This is a decrease of 23% compared to the previous 5 years. Despite this, the trend for total production and value of vegetables is rising slightly. (www.ausveg.com.au)

2.2 LABOUR SHORTAGE ISSUES

Underscoring the main study topic, "The Role of Mechanisation in Horticulture", are the problems based around farm labour. The cost of labour is ever increasing and the ability to find willing and competent workers is becoming more difficult. The minimum hourly wage for casual labour is around $17.60 (this varies slightly between States).

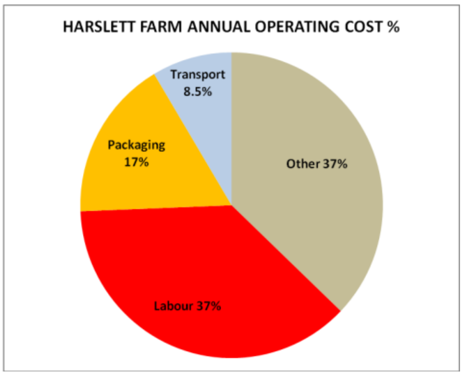

Fig 2.1 The Harslett Farm breakdown of costs. This is probably typical of most Australian vegetable farm.

From a non agricultural person's perspective the obvious solution would be to increase wages. A salary for a permanently employed labourer of between $25-35 000 per year is not acceptable for most people in today's society. Labour is around 40% of our farm's total expenditure. Many vegetable enterprises would have a similar cost structure. It is fair to say that the industry in general could not afford to simply raise wages significantly in the short term.

It is not relatively low wages alone that are causing a shortage of labour in the industry. The problem is more widespread than just the agriculture/horticulture industry. All employment sectors that rely on what society perceives as lowly skilled labour are struggling to fill vacancies. There are various factors as to why working in horticulture is not an attractive career choice. The reasons vary between individuals. They probably include a combination of some of the following:

- Low wages.
- Physically hard work.
- The work is often repetitive in nature.
- Some of the work has very little mental stimulation.
- In many cases there is little scope for career advancement.
- The work is often in the outdoor environment.
- Some people don't like to work in a team environment.
- The work is usually away from city locations.
- The work is often seasonal.
- Many employers expect employees to work inconsistent and long hours.
- The general public perception is to "look down" upon farming and farm labouring as a career.

Each employer needs to ascertain what they can offer that will attract the people they want. There are positive aspects to working in horticulture so employers and the collective industry need to identify and highlight these. They may include:

- Farmers have the choice to pay a higher wage for people they want to keep.
- The satisfaction that can be gained from being a part of growing food.
- There is scope for some employees to take on extra responsibility.
- The physical nature of the work.
- Working in the outdoors.
- Relatively low mental stress.
- Working in a team environment.
- Some work can have a low skill requirement.

- Many of the horticulture regions are located in areas where the cost of living is lower.
- Some people only want seasonal work.
- The work may be in an area that the individual's family come from.

It is quite striking how many positive aspects are also negative reasons to work in the horticulture industry. It goes to show that it depends on the individual.

Employers also need to think of ways to make working for them a more attractive prospect. There is a wide variety of options. Some that I have come across include:

- Providing accommodation.
- Providing transportation to and from work.
- Working less hours with the same pay in off-seasons.
- Paying higher wages.
- Providing year round work.
- Employers working in the field alongside employees when possible to build morale.
- Allowing extra holiday time in off-seasons.
- Providing health care benefits (not so applicable to Australia).
- Paying incentive based bonuses.
- Providing farm equipment for personal use at low cost.
- Sponsoring foreign workers' visas.
- Providing job opportunities for family members (not so applicable to Australia).
- Allowing produce for personal consumption.

The Government has acknowledged that it is not a simple case of raising the wages to attract people to the industry. It deserves credit for the changes it has made to work visa rules over the past few years. Of most relevance are the changes to the working holiday visas. In recent years the Government has allowed a drastic increase in allocation of temporary working holiday visas for young foreigners from certain countries. In the year 2007/08, 157 574 'working-holiday maker' and 'work & holiday' visas were granted (www.immi.gov.au). I was unable to quantify how many of the entrants on these visas spend some time working as horticultural labourers, but there is a significant number. The rule accompanying this, namely, if an individual works on farms for 3 months they can extend their visa by an extra year, has had a very beneficial effect on the industry. Because of the seasonality of much of the work, many backpackers often end up doing jobs that Australians would not want to do (in more than just horticulture). An added benefit is that backpackers end up spending most, if not all of the money they have earned before they leave the country thus boosting our economy in other ways.

More recently the Government decided to allow trials to bring in Pacific Island labour on a seasonal basis. The trial guest labour scheme will allow 800 Pacific Islanders into the country annually to harvest fruit and vegetables on a temporary basis. The employer will be expected to pay minimum Australian wages, many of the associated expenses and provide a level of pastoral care. This will have a very beneficial effect on the horticulture sector, but presumably these people will not spend their earned money as freely as backpackers because they will want to take it back to their country. The Government is approaching this trial as a means of helping to fill the unskilled labour shortages, but also as a form of aid to developing Pacific Island nations.

2.3 WHAT OTHER COUNTRIES ARE DOING TO FILL THE LABOUR SHORTAGES

UNITED KINGDOM/WESTERN EUROPE

To date, the European Union (EU) has been in an expansion mode. The countries that join are almost always less developed, so the standard of living and average income is lower than that of the western members of the EU. The migration rules for countries within the EU are very relaxed, so the more affluent countries rely very heavily on migrant labourers who are willing to do the work their own citizens don't want to do and at relatively low wages.

There are some interesting trends associated with this. It seems that once citizens of a lower income country have been working in the developed western society for a couple of years, their expectations become similar to the natives of the host country. Therefore they no longer want to do the type of work for the pay they are receiving. There are also many who save up enough money in a couple of years to move back to their homeland and start a new life. This hasn't been a great problem to date because the EU has been expanding thereby resulting in new source countries for the type of labourer required.

The minimum wage in the United Kingdom (UK) is low (AU$15-20) compared to the western countries on the European continent (AU$30+). When the UK Stirling was stronger compared to the Euro there was incentive for labourers to go to the UK. The closer the English pound comes to parity with the Euro, the less enticing the idea of temporarily working in the UK becomes.

On a side note; I had a UK farmer express to me the opinion that if and when Turkey enters the EU, he thinks the public will react negatively to a massive influx of people with different colour skin and a very different culture.

UNITED STATES OF AMERICA

The United States (US) has relied heavily on legal and non-legal Mexican labour for a long time now. There are currently estimated to be 27.6 million legal migrant workers and 11.2 million illegal migrant workers in the US (*USA Today, 31/7/08*). It would not be an underestimation to say that their input underpins the US economy.

Having lived in the US twice and visited on three other occasions, I am still amazed with the size of the growing divide between the haves and have-nots. The official minimum wage for California is US$8.25/hr. This is amongst the lowest of any western country and yet there is still a massive problem with people trying to get across the southern border to escape the poverty in Mexico. In reality, most migrant workers in horticulture would make more than the minimum wage because of the piece rate system that most farmers use. Still the net effect on agriculture, particularly labour intensive horticulture, is that their cost of production is lower than other western world countries.

Any tightening of US border restriction will decrease the supply of labour, forcing the cost up. With time the Mexicans will develop the same psyche as the average "white American" and will not be as willing to do the same types of labour, which will also be a catalyst to increase labour costs. The cost of labour does get higher the further north one goes from the Mexican border.

While there is political rhetoric about slowing the flow of people across the Mexican border, in reality, not much is being done because their contribution to the economy is invaluable. I did not see a single case of a "white American" doing the physical labour on a farm. It is regarded as Mexican work and it would be impossible to find 'white people' to do the work because of the stereotype and culture that the work has developed. It is possible to construe this as a form of racism.

There are plenty of examples of American farming companies moving some or all of their operations to places where the costs of production, including labour is lower. Mexico and Chile are prime examples. There is an element of seasonal continuity of supply associated with these moves. A Salinas farmer I spoke to who has some operations in Mexico pointed out an unexpected down side of this approach. The American buyers know the cost of production is lower, therefore they demand a lower price, making the farmer no better off. The vegetable industry in the US has not experienced the price rises that the consumer has come to perceive about the increasing cost of food because there is a general oversupply in US market. Many farmers are presently doing it tough because of the rapid increase in their input costs.

CANADA

Canada also struggles to find enough seasonal labour. Their problem is exacerbated by the drastic seasonal variation making their growing season short. For nearly 30 years they have used a "Seasonal Agricultural Worker Program" (SAWP). Each year around 18 000 Mexican and Caribbean workers come to Canada guaranteed a minimum 40hr working week and are provided with airfares and accommodation at the farmer's expense. They are treated like Canadian citizens while in the country, but can only stay a maximum 8 months per year. Most return year after year. The wage is at least Provincial minimum, but it is negotiated between the Canadian Government and that of the country of origin. The system is almost identical to that to be trialled with Pacific Island workers in Australia.

In more recent times the government has allowed an influx of unskilled labourers into the country under a new program known as the Low Skills Program. This program has very few rules compared to the SAWP. The mining boom has created a vacuum for unskilled labour in sections of the country.

The efficiency of many Canadian agriculture sectors is hampered by a short growing season. This makes it difficult for them to compete with many foreign lines of produce. There is a growing consumer culture of buying Canadian grown. This together with some Government regulation have helped to sustain some sectors.

NEW ZEALAND

Quite strangely, New Zealand has a relatively low horticulture minimum wage (NZ$11/hr) for the level of their economy. The farmers there are in desperate need of labourers but have difficulty attracting potential workers. The current upsurge in the dairy industry has created a drain on horticulture labour and dramatically increased land prices.

Their government has turned to temporary Pacific Islander labour in a bid to get a supply of willing labour. Perhaps taking an approach like the Australian government making it easier for foreign backpackers to get temporary work visas should be looked at. They also need to address their low minimum wage for a developed nation.

The horticulture industry may need to evaluate their future. Heavy reliance on exporting, labour issues, land competition with the dairy industry, dramatically increasing freight costs to distant markets and increasing environmental restrictions are all working against the industry.

CHINA

Farmers in China are still regarded as occupying close to the lowest stratum of society. Evidence of this was when I was introduced as the CEO of Horticulture Australia on a visit to a local agricultural Government official because of their perception of farmers. The government has made significant changes since 2003 that have all favoured the well being of farmers. They are loosing a huge number of people to the cities, but with a small investment in mechanisation, technology and infrastructure they will be able to compensate this loss for the time being. Increasing their average farm area would also help their efficiency greatly. While their cost of labour is very low, it is on the rise. They have a massive population that is rapidly increasing in affluence and demanding more and better quality food. I believe this will keep China's net impact on world agriculture and horticulture positive. Consequently, their low cost of labour should not be a significant issue to most Australian farmers.

JAPAN

Although I did not visit Japan as part of the scholarship I am somewhat familiar with the country. An article in the New York Times (15/8/08) was relevant to this topic.

The natural Japanese population could fall by as much as 36% by 2055. To add to this decline is the significant ageing of the population. Already, industries including vegetable farming are experiencing shortages of labour. The farmers are turning to itinerant labour from China and are soon to include the Philippines to fill the labour shortages. They are choosing labourers from these countries because there is potentially a plentiful source, they are willing to do the physical low skill work and they are willing to do it for low wages.

In all of these countries listed above farmers have an external source of willing and/or cheaper labour compared to their domestic country average. This does not hide the fact that there are going to be labour shortages and increased costs in the future. I am convinced that increased mechanisation and possible future robotics are part of the solution to reducing this problem.

Despite all this, a good philosophy for any employer to remember is: "*You get the people you deserve*".

3. MECHANISATION AND ROBOTICS

'Good farmers don't look for excuses; they find methods to overcome challenges'.

If a farmer is considering moving towards mechanisation and automation they must have this attitude.

As previously stated, the shortage and cost of labour issues were the underlying motive for looking at the topic of mechanisation in vegetable production. The following section is devoted to where the industry is at, where it is headed and why it is moving towards mechanisation and to a lesser extent robotics.

There are two fundamental obstacles to adopting mechanisation. The first is the capital expense. Then there are the changes in agronomic practices that will usually be required to increase the average quality and decrease the standard deviation of the quality to allow machines to work optimally.

3.1 MECHANISATION – JUSTIFYING THE EXPENSE

A dilemma that faces any farmer when they have to make an investment is; can it be economically justified? The most obvious potential benefit from mechanisation/automation is the reduced labour cost. Until the machine has been bought, put into use and running at full potential, it is difficult to calculate what the exact labour savings may be.

After seeing mechanisation in action around the world, I am convinced that the greatest economic benefit in adopting mechanisation is the increased standards of agronomic practices required to allow the machines to work optimally. Machines require the crop to be of high quality and have a low standard deviation from the average specification. This invariably means a better crop that will bring higher returns.

There are several less tangible economic benefits that may well result from investment in mechanisation and should be part of the investment justification, such as:

- The cost of labour is going to continue to rise.
- The supply of people that are willing to do the type of labour is diminishing.
- The human capital that a farmer has can be reduced or production expansion with current human capital becomes a more attractive proposition.

- A machine will work at a constant speed causing the remaining human input to work at a constant and reliable speed.
- Present equipment needs repairing and eventually replacing at some stage. There are real costs involved in maintenance without switching to mechanisation.
- The labourers will have an improved attitude if they are doing a more desirable job.
- Labour management is invariably one of the most challenging aspects of farm management. Reducing labour requirements makes management less stressful.

3.2 MECHANISATION AND PRECISION AGRICULTURE

If a farm operation moves towards mechanisation and/or robotics the need for precision techniques increases. When humans are doing the physical work and making the operation decisions there is a greater margin for error. A person can make a judgement on when adjustments need to be made to a given process. Mechanisation and robotics reduces the human input and invariably reduces the margin for error. To compensate for the reduced margin for error the variables involved in the operation need to be kept to a minimum. Precision is the key.

For the machine or robot to work best, precision practices need to be implemented on as many aspects of the farming operation as possible. Minimising the standard deviation of a crop yield is as important as improving the average yield. Increased uniformity of a crop in most cases will result in increased quality and consistency of produce. This will result in better returns for the produce.

When making the decision to switch to mechanisation the farmer needs to weigh up to what degree the operation should be changed to suit the machine versus changing the machine to suit the operation. Usually it will be a combination of the two. Farmers that are growing crops of high quality and consistency are usually using certain practices for good reason. If this is truly the case, then the emphasis should be on making the machine fit the situation. Having said this, it is natural for farmers to become complacent about their need to improve and change their practices. Many use the rationale; if what they are doing works, why change. How open a farmer’s attitude is to change may be crucial to whether mechanisation can be made to work on their farm.

When a new machine is in the development stage the key is to make a machine to fit a situation. In many cases the best results are achieved by letting the farmer design a machine because they know what they want as the end result. The next step is to let an agricultural engineer refine the design.

3.3 ROBOTICS IN AGRICULTURE

Robotics is a level above mechanisation in terms of autonomy. Mechanisation involves machines doing the physical work while humans still make the decisions. Robots are designed to eliminate the human input in the physical and decision-making processes. They rely on various types of sensors collecting information and then computing this to carry out the desired, repetitive operation. There are some key attributes that a robot requires to be of use:

- Autonomy – The robot needs to have sufficient computing power to think for itself. It must be self-powered and propelled. Therefore it will need to have a large enough power source.
- Intelligence – A robot needs to be able process the information collected by sensors and compute this to enable it to act with appropriate behaviour.
- Adaptability – As part of a robot's intelligence it needs to know how to adapt to different situations that confront it. There are always going to be undesirable scenarios involved in outdoor agriculture. These may be weather, terrain or the crop itself.
- Self-awareness – Robots need to be aware of the consequences of their actions and have mechanisms to allow graceful degradation. Graceful degradation is a term that refers to the robots ability to know why, when and how to stop operating to minimise damage to itself or the surrounds.
- Reliability – Because most agriculture is in open and variable terrain, robots are subjected to hostile conditions that they must be able to withstand.
- Fleet management – They need to be easy to maintain and repairable.
- Communication – Individual robots need to be able to communicate with a base and other robots.

There are some traits that a robot designer must keep in mind;

- Size – Some estimates are that 90% of energy used in tillage is to repair damage caused by machines. This favours the use of small robots. Limiting size will also limit the cost; making it more affordable to a greater number of farmers.
- Be able to work when required. Examples of this may be at night or under extreme temperature conditions.
- Small, duplicated robots will tend to be more effective. They are more adaptable to terrain and the entire operation does not rely on a single robot.

The prohibitive cost of current technology that allows robotic autonomy is the limiting factor in widespread use of robotics in agriculture. Another limitation is the major shift in skills required to operate and maintain robots compared to those a farmer typically has.

These restrictions are not being completely prohibitive to those farms taking that advanced leap in technology. Robotic technology is rapidly advancing. Some of this is in response to specific agricultural development, but most comes from adoption of advancements in technology from other industries. As the agricultural use of robotics becomes more widespread, the cost of the technology will decrease. Robotics does have a future in agriculture, including in vegetable production.

3.4 MECHANISATION - PLANT ESTABLISHMENT

DIRECT SEEDING VERSUS TRANSPLANTING

Transplanting is the most common method used in Australia for plant establishment. This is not necessarily the case in the major vegetable growing areas around the world. There are some real benefits to plant establishment via direct seeding. They include:

- The seeding process is fully mechanised.
- The plant will grow a far more extensive root system with a more natural tap root, improving growth rate, water use efficiency and nutrient uptake.
- The plant doesn't undergo transplanting shock.
- Transplanted root systems are susceptible to physical root damage when entering the ground. This is an ideal site for disease infection.
- There is potential to make a more uniform crop when humans manually cull the non uniform plants after germination (it is normal practice of put out more seeds than necessary to allow for uneven germination).
- Rogue weeds can be chipped while thinning is occurring.
- The more efficient water uptake leads to less frequent irrigation, thereby decreasing leaf diseases.

The drawbacks to direct seeding include:

- Not all vegetables have a fast enough germination rate to allow this practice.
- The growing season can only start when the environmental conditions are suitable (transplants in nurseries can extend a growing season significantly).
- Soil preparation needs to be perfect.
- Environmental conditions need to have little variation between seeding and establishment (no heavy rain, temperature, soil temperature).
- The process of thinning is very labour intensive.
- The plants will be in the ground longer, although not as long as it takes to grow a seedling in the nursery. It is not necessarily correct to assume they use more water or nutrients because the better root systems of direct seeded plants are more efficient at water and nutrient uptake.

- Weed control is more difficult because herbicide use is more restricted and the plants are in the ground longer.

The reasons transplanting is the most common method used in Australia are a combination of the following:

- Many of the vegetable growing areas are subject to variable temperature conditions and heavy rainfall events at unwanted times.
- Land is expensive so there is often a desire to grow multiple crops per season.
- The growing season is limited by weather, so the fastest crop turnaround is desirable.
- Labour is expensive and limited for the thinning process.
- Some lines of transplants are grafted.
- Traditionally that is how it has been done.

Given that a significant proportion of the world's vegetables are grown by direct seeding, including some of the major growing regions, perhaps farmers need to look more closely at direct seeding on an individual farm basis.

METHODS OF TRANSPLANTING

There are three ways to transplant:

- Using the fully manual method.
- Using the semi-automatic machines where the plants are fed manually into the mechanical transplanter.
- Using the fully automated system where the plants are extracted from the trays mechanically and planted by the mechanical transplanter.

For the most part, manual planting is a thing of the past on medium to large scale and more efficient vegetable farms. The system is too labour intensive, human handling practices cause unnecessary damage to the seedlings and humans put the plants in the ground unevenly. With current technology manual planting still has a place on farms that plant into plastic mulch.

Semi-automated machines are the most common method, but they do have a significantly higher labour input than an automated system. The mechanical and/or robotic technology is reliable and affordable enough that some farmers have made the investment to automated machines, primarily to cut the labour costs. This trend will inevitably continue.

Because Australian systems rely heavily on transplanting we are near the forefront of automated transplanting machine development.

3.5 MECHANISATION - WEEDING

This is a significant part of my study topic. It is covered extensively in Chapter 5 - Alternative Methods of Weed Control.

3.6 MECHANISATION – SPRAYING

The technologies presently available and used in the Australian vegetable industry seem to be up to date with current world technology.

The only technology I encountered that I was not aware existed in Australia was the Danfoil of Denmark. Their units use 30-100L/ha of liquid. The principle is that the liquid is mixed with the air that forms the air blast, which splits the liquid into very fine droplets to give excellent spray coverage. The air blast does reduce drift compared to a conventional sprayer. The other significant advantage is that it is possible to cover a large area with a limited tank size.

The use of helicopters and aeroplanes to carry out spraying is a little more widespread in the US, mostly because of the scale of farms. The advantage of these methods over ground rigs is mostly in the ability to cover a large area quickly and the opportunity to spray if the ground is too wet for driving on. In most cases, ground rigs are the most cost effective and give the most even coverage. Canopy penetration comparison is dependent on what type of ground rig is used. Helicopters and aeroplanes do have significant down drafts that aid canopy penetration.

The most notable observation that the Australian industry needs to take heed of, is the level of regulation and restrictions on American and European farmers. The level of documentation and justification processes for chemical use is something that will probably increasingly be an issue to the Australian industry. The European farmers are faced with the tightest restrictions on the types of chemicals they can use. Australia seems to fit somewhere between Europe and the US in this regard. I am convinced that with increasing environmental restrictions we need to be mindful that our ability to use some chemicals groups will inevitably become more limited.

3.7 IRRIGATION

Australia is well known around the world for our water limitation. Because of this, Australian horticulturalists for the most part have already embraced the most efficient water-use techniques for application. The major limitation to farmers using best practices and technology for agriculture in

Australia is their unwillingness to adopt change. The advancements that will come in the foreseeable future are irrigation decision-making tools and automation of application controls. Technology in this field is rapidly developing and is already being implemented to varying extents within Australia.

3.8 MECHANISATION – HARVESTING

Machines used for harvesting can be broken into three levels of technology; harvesting aids, mechanical harvesting and automatic harvesters.

HARVESTING AIDS

Harvesting aids are machines that assist to make the job of humans easier and more efficient. Mechanical harvesting aids are widespread in their use. Every vegetable farmer uses these to some extent in the harvesting process. They will continue to have their place well into the future. There is scope to use better technologies to make these more efficient. Every technological improvement on harvesting aids makes them more like a mechanical harvester.

MECHANICAL HARVESTERS

Mechanical harvesting is the area in which I see the most potential for technological improvements in vegetable farming in the foreseeable future. A mechanical harvester is one that does the majority of the physical work, but still requires humans to carry out the decision-making process.

A large proportion of my self-study travel was devoted to looking into machines for harvesting of leafy vegetables. I found that the machines designed for this purpose basically work on the same principle. Some form of knife is cutting the base of the plant, the plant is raised by some form of belt thereby leaving the plant to be tidied and cleaned by humans. Most root crops grown in developed countries use machines based on these principles. Machines with similar concepts are becoming increasingly used for leaf crops. The limitation is not the technology of the machine, but the requirement to grow consistently high quality and even crops to allow the machine to be utilized in an efficient and economical way.

A harvesting machine will work best under uniform conditions. Minimizing the deviations from uniformity is the key to the success of the machine. In an outdoor environment this is often challenging. The uniformity needs to be in the crop and the soil bed it is planted in.

Fig 3.1 Asa-Lift (Denmark) cabbage harvester.

Fig 3.2 Lakewood Machinery (Michigan) celery harvester.

Fig 3.3 Ortomec (Italy) mini cos harvester.

If the farmer wants a harvesting machine to work, there will need to be some flexibility and compromise between agronomic practices and the machine design. Usually a farmer performs an agronomic practice for a good practical reason. Invariably these will need some level of modification to suit the machine. Deciding on this level of compromise to growing practices and actually implementing them successfully is a real challenge for most farmers both psychologically and practically.

From my travelling and talking to foreign machinery makers I have come to realise that mechanisation is actually more prevalent in the Australian vegetable industry than I thought. There is a definite culture of not sharing information in the vegetable industry in Australia. I put this down in part to the relatively closed domestic market for fresh vegetables in Australia. The potential benefits from having a mechanical system can give a real advantage over competitors and hence the lack of information dissemination.

ROBOTIC HARVESTERS

Robotics is where the machine does most of the physical work and carries out the associated decision-making. This is the future for vegetable production, but at this stage it is mostly limited to experimental research. There have been rapid developments in recent years and will continue to be so in the field of optics, sensors and computing power that will enable machines to start making more intelligent decisions. The recent upsurge in world agriculture due to a perceived world food shortage and biofuels may help to accelerate the development of agricultural automation. Suddenly governments, research organisations and corporations are paying more attention to agriculture and are willing to invest in technology for agricultural purposes.

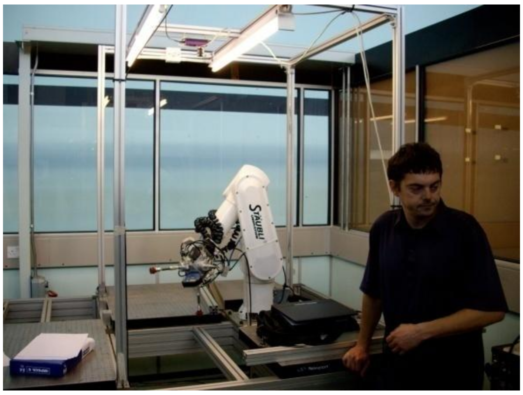

Fig 3.4 An experimental robotic mushroom picker being developed by Warwick University (UK).

SECTION B – ALTERNATIVE METHODS OF WEED AND DISEASE CONTROL

Integrated pest management (IPM) has a slightly different meaning to most people in agriculture. I consider it to be: *The control of pests (insects, diseases, weeds and animals) through the integration of available control options in the most environmentally sustainable way, while maintaining crop protection to a threshold that is economically acceptable*. A definition like this inherently allows for a wide degree of tolerance levels. Variations exist between individual farmer's definitions of pests, environmental sustainability and an economically acceptable threshold.

My experience is that IPM is a well known concept for insect control. It is widely adopted to varying degrees in agriculture. For this reason I have chosen to concentrate on IPM for diseases and weeds.

4. IPM – ALTERNATIVE METHODS OF DISEASE CONTROL

IPM for insect management is a concept that has been widely adopted to varying degrees in agriculture. It is relatively easy for a farmer or a consultant to identify beneficial and problematic insects and quantify the damage they cause. The farmer can then set a control threshold that they are comfortable with. The biggest problem with IPM for disease management is that beneficial pathogens are not easily identified and problematic diseases are not usually visible until they have expressed themselves in the form of crop damage.

For a farmer to start to think about IPM for disease (fungal and bacterial) management they must grasp the notion that, just like insect IPM, there are beneficial and problematic pathogens. The inability to readily identify the beneficial pathogens and the affect they are having is a very real and practical limitation to adopting the best control options.

Most fungicides registered for vegetables are preventative as opposed to curative. Therefore for the maximum effect they need to be applied before disease symptoms are expressed. This works against the principles of IPM for disease control.

My experience with chemical control options for disease is that the chemicals are not developed to be specific to the target pathogens. If the chemical companies have taken this into account, then they do not publicise the fact well enough for general farmer uptake in spray programs. Insecticides or herbicides developed in recent times have been designed to specifically target a range or individual species of pests.

My conclusion from looking into the topic around the world is that the concept of IPM for disease control is struggling to gain any footing because the diseases are not easily identified and the chemical control options are not satisfactorily advanced to be a target-specific tool. Having said this, there are factors that should be considered to best utilize IPM for disease management with current knowledge. These are covered in this chapter.

4.1 HEALTHY PLANTS

Perhaps the most important, but often overlooked, factor in disease control is to ensure that the plant is growing without any stresses. A healthy plant will have the best natural immune system. Ensuring optimal moisture, nutrition and environmental conditions suitable for the species/cultivar will go a long way to avoiding many diseases.

4.2 PLANT CULTIVAR CHOICES

Plant cultivar disease resistance is one of the most important tools in disease prevention. Disease resistance is close to the top of most vegetable plant breeders' priorities. Each line of vegetable has a variety of diseases that are problematic. Plant breeders are mindful of these. Take for example lettuce breeding. It is fair to assume that two traits that all seed company's breeders must incorporate in developing new lines are Downy Mildew resistant and *Nassanovia* lettuce aphid resistance.

When possible, choosing a disease resistant variety should be central to an IPM strategy for disease control.

Related to the principle of plant breeding is the idea of genetically modified (GM) vegetables. There are several reasons why I think that GM plants will become widely grown around the world. When considering how the world is going to feed itself with increasing population and affluence there is immense potential for inserting genes that will result in yield increases. From a farmer's perspective there is scope for making the crop growing easier, with less input costs. This has positive environmental ramifications. As consumers become increasingly aware of the relationship between disease control and the use of pesticides their acceptance of GM food should increase.

A prime example of how GM may be used for vegetables in the future for disease control is the significant work being done in the UK to introduce a gene to potatoes to make them resistant to blight. Although it is still many years off commercial release it does show potential as being a new way to control a disease that has caused yield reductions for centuries.

There is widespread experimental research being conducted around the world by various companies and education institutions on numerous vegetables. The technology is well enough understood these days for it to be relatively simple to insert foreign genes to plants. The major expenses come in the field trial work to prove the safety of the new variety. There are countless lines of vegetables with large numbers of pest problems to contend with. Choosing which vegetables to invest the money into and for what genetic purpose is going to be a challenge for development of GM vegetables. To date the only commercially used genetically modified vegetable was a tomato grown in the US and several other countries in the mid 90s. A gene was inserted to the tomato plant to stop the fruit from softening. It was grown for several years but failed to meet specification expectations. At the time there would have also been strong public opposition to the notion of the public consumption of GM tomatoes, particularly in Europe.

4.3 CHEMICAL CONTROL

Chemical control is the most common and often most effective form of disease control. New disease control chemicals that are developed are designed to be more target specific to individual or groups of pathogens. Despite this it is fair to assume that there will be some effect on non target species. This lack of understanding can be the downfall of a sound IPM strategy for disease control.

There are various chemical application practices that can reduce the unintended effects on beneficial pathogens:

- Disease modelling – The use of predictive disease modelling to match environmental conditions to potential pathogen attack. Black Spot warnings in apples are a classic example.

Horticulture Australia is funding projects for disease models in white blister in brassicas and septoria in celery.

- Application timing – Put some thought into when to apply chemicals to have least affect on beneficial species. An example of how to minimize the effect on soil microbes is to spray in the nursery or wait until the plant canopy covers soil surface. Application timing relative to UV intensity and irrigation/rainfall events can be relevant.
- Spraying methods – There are various methods to making chemical application more effective. Air assist spray booms, twin jet nozzles, use of wetting/sticking agents, spray water volume, nozzle pressure, spray water pH, time of day, etc can all have an affect on efficacy.

4.4 FARM CULTURAL PRACTICES

There are many aspects of on-farm practices that can influence the disease related health of crops. These are:

- Crop rotation - Because most vegetable production is a monoculture, it is important to rotate crops to break disease cycles. The length of the break required varies between crops and diseases. It can be as long as 12 years in some carrot growing regions to as short as allowing enough time for crop residue breakdown in the soil.
- Farm hygiene – Control of volunteer crops and weed species related to the intended crops is important for breaking disease cycles. Controlling insects that act as disease vectors is also a consideration.
- Avoiding crop damage – Any physical damage to a plant opens up a site for pathogen infections. There are various means by which a plant can sustain damage. Common methods include mechanical/hand weeding, insect/animal/nematode damage and primary unrelated disease infection sites.
- Irrigation method – Overhead irrigation increases leaf wetness and canopy humidity favouring some diseases. Drip irrigation often leads to extended periods of butt wetness favouring other diseases.
- Irrigation timing – The time of day that irrigation is applied can strongly influence the humidity in a crop canopy, favouring some disease infection potential.
- Plant spacing and density – Increasing space between plants will increase air movement and help to minimize humidity in the crop canopy. Lower humidity will mean less favourable conditions for most diseases.

- Planting depth – By planting transplants slightly out of the ground it will minimize leaf contact with the soil, thereby decreasing disease development.
- Soil pH – Each crop has an optimal pH range for plant growth. Soils should be amended to suit this range.

4.5 CLEAN SEED

In many cases the seed used is the source of the disease infection. Taking steps to ensure clean seed can be the most important step to maintaining good crop health. Most seeds are produced by commercial companies so there is little scope for the farmer to impact on this process. However, if the farmer knows of a problem they can do something about it.

4.6 SOIL STERILIZATION

There are several means of sterilizing a soil of plant pathogens. Fumigation was a method widely used in the past. The phasing out of these chemicals for environmental reasons has limited its use. Steaming of soils, whereby the soil is heated with steam to a temperature that kills soil pathogens and weed seeds does work, but it is generally too energy demanding to warrant the effort. It will also kill the beneficial soil microbes.

4.7 BENEFICIAL PATHOGEN INNOCULATION

Inoculating the soil or nursery seedling with beneficial microbes is increasing in conventional farming. There are a few factors that are pivotal to making this work:

- Choosing the right species of beneficial microbes to suit the soil, environment and disease pathogen.
- Modifying chemical use to minimize the damage to the beneficial microbes.
- Application technique.

4.8 BIOFUMIGANTS

This technique is more widely known for its use as a method of nematode control, but there are examples of plant species being grown and incorporated into the soil to control diseases. HAL is presently funding a research project into using BQ Mulch (a mustard brassica) as a means of controlling soil borne sclerotinia.

5. IPM – ALTERNATIVE METHODS OF WEED CONTROL

Weeds are defined as an unwanted plant species growing in the present crop. They compete for light energy, water and nutrients. They can also promote disease by increasing canopy humidity and contributing to a weaker crop plant. Weeds make the harvesting process more difficult and time consuming. Weeds also have a negative psychological effect on the farmer, farm labourers and people who see the crops.

Every farmer has a different threshold for what they consider to be an acceptable form of weed control. This can range from no tolerance to a complete lack of concern for weeds.

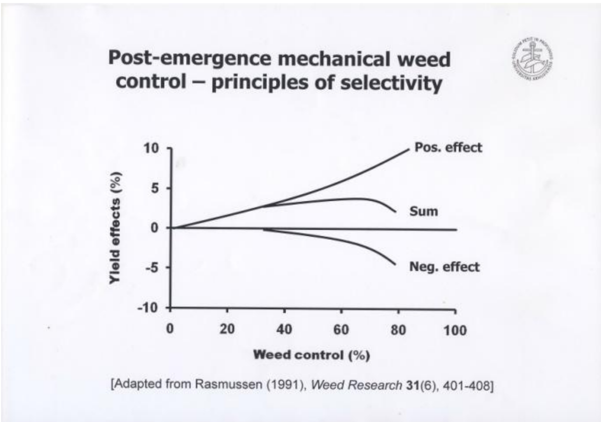

Fig 5.1 Taken from a presentation by Bo Melander, Aarhus University Denmark. While it refers to mechanical weeding the principle is much the same for all forms of weed control. Farmers need to decide what threshold they are comfortable with for weed tolerance.

Using my definition of IPM, all farmers are using varying degrees of IPM for weed management. Herbicides are the most obvious form of weed control in conventional farming. Herbicide development is quite advanced, in that there are many chemicals that target specific ranges of weed species. This can make them quite a useful tool in IPM weed management. By considering herbicides to be one of the tools of an integrated weed management system, they will become more effective to the extent that they may not be required.

There are many varied devises for controlling the inter-row spaces of crops. The biggest challenge that present technology struggles to overcome is the weeds in the intra-row spaces between plants.

This chapter looks at the different forms of weed control that I have become aware of. It points out the pros and cons of each method. Every farmer in every situation has to make a decision on what is best for them and at what cost the desirable level of weed control can be achieved.

5.1 HERBICIDES

This is the most common method of weed control in conventional style farming.

Pros:

- Can be effective. In some crops, some chemicals can eliminate the need for any other weed control methods.
- Fast to apply.
- Relatively low cost in most cases.
- There are many that have a target specific range of weed species.
- Decreases the need for in-crop weed control requirements.
- Amongst the lower carbon footprints of all weed control options.

Cons:

- Herbicides can have a detrimental effect on the crop.
- The chemicals used often don't control the full spectrum of weed species.
- Accurate timing is usually required.
- Some chemicals can affect beneficial soil microbiology.
- Some chemicals have a residual effect on the soil.
- Some chemicals can have detrimental environmental impacts (air or water).
- Weeds with chemical resistance are becoming an increasingly common problem.
- The cost of the chemical and application is increasing.
- Some chemicals can be dangerous to humans.

Farmers in Australia need to be mindful that environmental and negative social perceptions are going to increasingly restrict our ability to use many types of herbicides. Rightly or wrongly, the trends in Europe suggest that we need to be looking for alternative methods to herbicide use as a practical option.

5.2 HAND WEEDING

This includes physically using your hands or some type of hand operated chipping hoe. On a global scale this is still by far the most common form of weed control. Even in efficient modern agriculture there is still some place for it and is still very common in organic farming.

Pros:

- Can control all weeds.
- No environmental impact.
- Can be used to utilise labour in spare times.

Cons:

- Very labour intensive, slow and expensive.
- Creates an opportunity for crop damage. This can have a yield effect and allow a disease infection site.
- Weeding is an undesirable and physically demanding job.
- May create an uneven bed surface for mechanical harvesting.
- Creates an opportunity for physical spread of disease.
- Increases the opportunity for a second flush of weeds.

It is an obvious conclusion that hand weeding is not an ideal solution to weed problems in modern agriculture.

5.3 MECHANICAL WEEDING

Mechanical weeding is not a new concept. It is the most cost effective method of removing weeds that have grown through the herbicides (if applied). Depending on the crops grown, it is fair to assume that many larger scale farms have some form of mechanical weeder.

Pros:

- Relatively cost effective.
- Fast and efficient for between row weeds.
- Low environmental impact.
- Breaks soil surface crusts that impede water penetration in some soils.
- Is carried out during the crop growing cycle.
- Some farmers who use mechanical weeding routinely only need to use herbicide within the crop rows.
- In many cases a fertilization process is incorporated into the operation.

Cons:

- Most devises only control weeds between the rows.
- Requires specialised equipment and labour.

- There is little margin for human or sensor guided error.
- Creates an opportunity for crop damage. This can have a yield effect and allow a disease infection site.
- There is an energy cost.
- May create an uneven bed surface for mechanical harvesting.

Control of inter-row weeds with current technology of mechanical weeders is relatively straight forward. There are various types of tynes which all have their place, depending on the situation. The biggest challenge to mechanical weeding is how to deal with intra-row weeds (the weeds between crop plants in the row). There are some technological advances that are already on the market or soon will be that will improve mechanical weeding.

HAND-GUIDED INTER-ROW WEEDING

There are variations in the method in which this is achieved. The basic principle is a manual guided mechanism to take some of the emphasis away from the steering of the tractor. This should allow greater accuracy of tyne placement.

SENSOR GUIDED INTER-ROW WEEDING

There are various companies that have developed camera sensors that recognise the crop rows and activate hydraulic rams to move the cultivating tines sideways to compensate for tractor steering movement. This allows for less operator error, decreases driver fatigue and allows significantly faster operation speeds. However it still only acts on weeds between rows. There can also be variable levels of crop row recognition.

I have encountered three companies that make such a product: Eco-Dan, Vision Weeding and Garford.

HAND-GUIDED INTRA-ROW WEEDING

A simple, yet effective method of intra row weeding is the use of tractor driven spinning tines that are manually moved sideways by someone sitting on the back of the unit. The model that I was introduced to is made by Univerco in Canada. It does have significant labour input and the speed is limited by human reaction time. A person can only do one row at a time.

SENSOR GUIDED INTRA-ROW WEEDING

This technology is still in the development stage but has started to hit the market. The principle is that real time cameras differentiate between soil and plants using colour or infra red. Then the computer identifies the crop plant from weeds by shape and size. A hydraulic hinged tyne or series of flames can then be used to eliminate the weeds. The Danish company that introduced me to these concepts (www.visionweeding.com) plan to integrate the units as part of an inter-row weeding machine that will also have the row recognition technology to keep it on track. At this stage it is difficult to predict what the cost of unit will be but it should be of particular interest to any vegetable grower that is struggling to control intra-row weeds. The hydraulically hinged tyne machine will be first to become available on the market.

The main advantage of the flaming concept is that the soil will not be disturbed, making a second flush of weeds less likely. Preliminary trials are suggesting that 1 hectare will use about 11kg of propane and about twice the volume of oxygen. That equates to roughly AU$150/ha.

A French company Sarl Radis is also working on the intra-row mechanical weeding using a horizontal light beam to sense the crop.

All of the real time camera guided machines rely on the weed species being a different shape and size to the crop. Therefore weeding will have to occur as soon after weed emergence as possible.

Fig 5.1 Visionweeding intra-row weed burner.

Fig 5.2 Sarl Radis camera guided intra-row weeder.

GPS GUIDED WEEDERS

Research is being done at the University of Copenhagen to develop the "Cycloid Weeder". This principle involves logging the exact position of the seed or transplant at planting with GPS. Then at weeding time the rotating fingers can avoid the crop plant. I believe the GPS referencing concept has a future, but question the Cycloid Weeding mechanism because of its mechanical complexity.

Fig 5.3 GPS guided Cycloid Weeder.

5.4 SOIL FUMIGANTS

Soil fumigants are a method of weed control that have been widely used in the past and are still actively used in some areas of the world. The two most common fumigants are *methyl bromide* and *metham-sodium*.

Pros:

- Will kill all weed seeds and pathogens it comes in contact with.
- Decreases the need for in-crop weed control requirements.
- Is efficient where plastic mulches are being use.
- Will help to control some soil borne diseases.

Cons:

- Has adverse environmental impacts.
- For the most part has been phased out in most of the developed world.
- Kills all soil microbiology, including beneficial organisms.
- Can be dangerous to humans.
- Requires a form of cover to keep in the soil while the chemical is active.

Farmers who are still allowed to use these chemicals should be thinking of alternative means of achieving the same outcome. Australian farmers are still allowed to use metam-sodium under plastic for certain crops. The time will come where it will be illegal to use and in any case their use should be affecting the farmers' environmental conscience.

5.5 AMMONIUM BASED SPRAYS

A method of post-emergent weed control in Cole crops being used in some places is an ammonium based spray. Cole crops include broccoli, cauliflower, cabbage, brussel sprouts, kohl rabbi, etc. The example that I encountered used a mixture of 75% Ammonium Nitrate (20% N content) and 25% Ammonium Tri-sulphate. It is applied when the crop is at the 5-6 true leaf stage. The spray is directed at the base of the crop and anywhere that mechanical weeding will not disturb. The spray will leave burn marks on some of the older leaves. Farmers that choose to use this method consider this to be mostly a cosmetic impediment to yield. By the time the crop is harvested the damage is barely noticeable.

Pros:

- A relatively effective post emergent control method for intra-row weed control.
- No environmental impact other than the energy required for the production process.
- Acts as a nitrogen and sulphur application process.
- Fast and efficient to apply.
- Does not disturb the soil and has minimal impact on the crop.

Cons:

- It works best when the weeds are slightly water stressed. Invariably the crop is also water stressed.
- The crop can not be overhead watered until the ammonium has had a chance to burn the weeds. This may take at least a day and the crop is water stressed at this time. Transplanted crops will not have had sufficient time to develop extensive root systems to allow extended, between watering, intervals.
- It requires accurate timing.
- It requires some investment in machinery.
- Some of the ammonium will volatilize before it gets a chance to be washed into the soil.
- Weeds with a waxy surface are likely to be more resistant. Fat hen (*Chenopodium album*) is one example.

5.6 PLASTIC MULCHES

This is a common method of suppressing weeds. It is widely used in high value crops that are in the ground for a relatively long season, such as, strawberries, trellis tomatoes, capsicums, etc. It is also a method commonly used by organic farmers. There are examples of some leafy vegetable growers using this method, but on a multiple use basis to justify the input cost.

Pros:

- It is very effective at suppressing weeds on the ground it covers.
- It decreases water evaporation from soil surface.
- It can reduce water logging during heavy rainfall events.
- It can be used for more than one crop in some circumstances.
- Soil fumigants can be used and contained effectively under it.
- It keeps crop canopy away from soil contact decreasing disease and soil contamination.

Cons:

- There is expensive outlay.
- It time consuming to lay and pick up.
- In many areas recycling options are limited.
- It reduces options for fast and efficient planting methods.
- The use of drip is the only method for irrigation.
- It reduces potential capture of natural rainfall.
- Weed control options in the crop holes are limited other than fumigation.
- The plastic is made from synthetic oils.

I have seen paper mulches trialled as an alternative to plastic. However these have never been widely adopted. A more promising development for a biodegradable alternative to plastic maybe a product called Mater-Bi. It is manufactured by Novamont in Italy, sold in Australia by Australian Bioplastics and is made from a mixture of cornstarch, vegetable oils and synthetic biodegradable polyester. Presently it is more expensive than plastic but does have the cost saving of not needing to be picked up and disposed of at the end of the season. I can't comment on whether there is any reduction in energy requirements to produce it compared to plastic mulch.

Another mulching idea I encountered on some baby-leaf farms was to apply 1-2cm of inert sand over the seed bed. This acted as an impediment to weed germination. The crop seeds did not have to be buried in the natural soil so there is no compaction to inhibit germination. The added benefit is that sand does not stick to leaves when harvesting occurs. There obviously needs to be a readily available source of inert sand.

5.7 CROP ROTATION

Crop rotation is probably more widely recognised as a means of disease mitigation. The concept is equally valid for weeds. The rotation should be between completely different families of crops or between crops and a green manure.

Pros:

- Different herbicides with different modes of action can be used.
- Herbicides may not be required.
- There are various non weed related benefits of crop rotation and green manures.

Cons:

- It may require a spell with no income crops.
- It may require owning or renting excess land to allow rotations.

A common rotation used by organic farmers is to spell land with a mix of rye and clover to pasture for several years between vegetable crops. This will allow some natural weed and disease suppression, a build up of organic matter and increased soil nitrogen.

5.8 PLANT DENSITY AND SPACING

Crop density and spacing can have a positive affect on weed suppression. Planting so that the canopy of the crop covers the most amount of ground without compromising yield will maximise the shading effect to suppress weeds. If the planting ground is level there is the potential to cross cultivate as a means of controlling intra-row weeds when the spacing and density pattern is even.

5.9 PRE-PLANTING KILL OFF

This involves preparing the land well in advance of planting and creating an environment for weed germination. Just prior to planting the first flush of weeds that have germinated are eliminated by herbicide, flaming or scarifying. This process requires the soil to have minimal disturbance before and during planting.

Pros:

- It eliminates first flush of weeds without affecting the crop.

Cons:

- The method requires advanced soil preparation and extra water to germinate the first flush of weeds.
- The land is out of production while the weed germination process is happening.
- Some weeds will have germinated but not emerged when the weed elimination process occurs.
- The bed surface may develop a crust that is not ideal for planting.
- The exposed bed surface is vulnerable to erosion.

5.10 STEAMING

This involves injecting steam created by diesel burning to the desired depth in the soil to create a temperature high enough to render seeds unviable.

Pros:

- It kills 80-90% of weed seeds in the treatment zone.
- It kills some soil pathogens.
- A method of killing weeds with difficult to control bulbs.
- It is compatible with organic techniques.

Cons:

- It requires high energy which is costly.
- It is slow to carry out. Operating at approximately 250m/hr.
- It only heats soil to approximately 85^{o}C which won't kill all weed seeds.
- It kills a lot of soil microbiology, including beneficial microbes.
- It can cause chemical reactions with some fertilizers potentially making the soil too salty for some crop seed germination.

A farmer I met growing baby leaf used this method of weed control. The machine uses 1500-2500L of diesel per hectare, plus the time and tractor involved. It also required a mains-water pipe to be linked to the unit.

A more efficient method of steaming is to apply in bands where intra-row weeding is not possible. Using this method still uses large amounts of diesel energy. The machine I looked at was used for organic carrots. It steamed a 12cm band, 6cm deep. If the planting density was 50 000/ha, 15mL of diesel would be required, plus tractor and labour costs per plant. The unit had a 2000L water tanks that needed refilling at each turn.

5.11 FLAMING

This is a process of burning a fossil fuel gas under a tractor mounted implement. The temperatures created for a very short time are sufficient to denature cell structure of the weeds. It is used as at pre-planting, pre-seed emergence or to burn off potato tops prior to harvest.

Pros:

- It eliminates all small weeds that have emerged.
- It is allowed under most organic certification rules.

Cons:

- Large amounts of fossil fuels required making a significant cost and a pollution issue (a UK example I saw equated to about AU$300/ha with propane, tractor and labour.)
- Only germinated weeds are controlled.
- It is a slow process to carry out.

5.12 SOLARISATION

The principle involves the covering the paddock with black plastic mulch and letting the solar energy bake the soil underneath.

Pros:

- This has the potential to make weed seeds in the heated zone permanently unviable.
- It is environmentally friendly other than the production of the plastic.

Cons:

- It requires hot climates with high solar hours.
- There can be no cropping in the paddock while this is being carried out.
- There is plastic waste to dispose of when finished.
- It will create hostile conditions for soil microbes.

5.13 NIGHT SOIL PREPARATION & PLANTING

The theory is that if the soil is tilled and planted in the same period of complete darkness, some light sensitive weed seeds will not germinate because light germination initiation does not occur. Apparently there can be a reduction of up to 30% in light sensitive weeds germinating. I don’t know which weeds species common in Australia are light sensitive. There are also some practical implications to doing the soil tillage and planting work in one night.

5.14 GLASSHOUSE PRODUCTION

Glasshouse production has become an increasingly feasible method of producing a variety of vegetables. Weeds are not an issue under this system.

Since the average consumer has become accustomed to blemish free produce there is a good argument for producing some vegetables in glasshouse systems. It allows almost complete control over inputs and eliminates most environmental risk aspects to production. There are some sound arguments to say that there is less impact on the environment per kg of product under this system. The trend of some large agriculture related companies investing in the infrastructure suggests the cost of production is comparable to outdoor systems.

5.15 GENETIC MODIFICATION

This is merely a theoretical option for a method of weed control for the time being. Some of the broad acre crops like corn, cotton, wheat, barely and soybeans have been genetically modified to allow broad spectrum herbicides like glyphosate (Roundup) and/or glycine/phosphinic acid (Basta) to be used on them. In theory this could be done to various vegetable crops. Since the resistance genes for these herbicides have already been isolated, in theory it would not take much to insert them into a vegetable. However it is very unlikely this will occur. The relatively small value of most vegetables lines would not justify the investment. There is also a level of public resistance to GM food crops around the world. Weeds are not considered the main problem for many vegetable lines and many farmers, so herbicide resistant traits may not be the most desirable GM trait.

6. CONCLUSION AND RECOMENDATIONS

In relation to mechanisation in the vegetable industry; my conclusion is that if you are serious about being involved in the industry in committed and long term way, then you need to embrace the idea of mechanisation and robotics. Labour will not become any easier or cheaper to source and machines are a valid alternative.

The most obvious cost saving of using a machine is the potential to reduce labour costs. I have come to the conclusion that the greatest economic reward comes from improving cropping techniques to cater for machines, that require high average quality, with low standard deviation in crop quality. For a machine to work the whole farming system needs to be of the highest quality, as often as possible. For a machine to work in a farming system the farmer has to want to make it work. Therefore the ideology "*Good farmers don't make excuses; they find ways to overcome challenges*" is highly relevant.

There are various other potential positive benefits to switching to mechanisation. There are also some drawbacks. The initial cost often involves a huge leap of faith. In many instances there may be a need to modify a crop growing system. These factors dictate that there must be a desire from management and staff to want to make a machine work.

When is comes to looking into alternative methods for weed and disease control there is a need for progressive farmers to realise changes will confront the industry with regards to limitations on chemical use. Rightly or wrongly, conventional chemical use will become more restricted due to social and environmental regulation.

There are many practical, novel and innovative methods for controlling weeds and diseases on farms. A whole system approach needs to be taken into account when implementing new weed and disease control methods to replace or complement present practices.

Plain English Compendium Summary

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Nuffield Australia Project No.:805	
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Objectives	I set out to find out some of the global trends in vegetable production and look at which of those are likely to have an impact on the Australian industry. I distinctly focused on production issues, with my main topics being mechanisation and alternative methods of weed and disease control.
Background	Labour is by far the greatest cost to most horticulture enterprises. It is becoming increasingly expensive and difficult to source quality personnel. How to alleviate the problems associated with this was the major topic for my study. Social and environmental pressure will increasingly restrict the use of chemicals we presently use. For this reason I was also interested to look at alternative methods for weed and disease control.
Research	I focused my personal study in the US and Europe. These are areas were production pressures are similar to those we experience. I wanted to see how they are confronting the issues. I also made an effort to see some more of how other farmers in Australia are tackling the issues. Information dissemination between vegetable farmers in Australia is limited. Once you start looking, there is innovation happening in our own back yard.
Outcomes	I am convinced that the best way to overcome some of the labour issues associated with cost and scarcity is to implement mechanisation. Implementation of mechanisation does have other tangible benefits to a production system. Alternative methods of weed and disease control need to be looked at on an individual basis. There are many innovative ideas out there on how to reduce reliance on chemicals or improve their efficacy by integrating various control methods.
Implications	Improved production practices are continually being made. Good farmers will embrace these innovations to their benefit. Mechanisation and alternative methods of weed and disease control are production issues that will increasingly filter into our industry
Publications	Vegetables Australia magazine. Jan/Feb '09 – Smart Growers Embrace the Future.

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