Robotics, Automation and Emerging Technologies for the Future of Australian Horticulture

An in-depth investigation of cutting edge existing, and near future technology and why growers need to rethink farming today

A report for

NUFFIELD AUSTRALIA FARMING SCHOLARS

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Executive Summary

AgTech is trending and appears on the topic list at any global agricultural event today. Terms such as robotics, automation, deep learning, machine vision, and blockchain are appearing in AgTech media articles, promising to revolutionise agricultural production like never before, claiming to be the solution to feeding a growing global population. Farmers are being warned that the fourth industrial revolution is coming, and agriculture, one of the most manual labour dependent industries, stands to be changed forever. Michael Dean, CIO of AgFunder (The World's leading online Agtech venture capital platform) explains:

"As with all industries, technology plays a key role in the operation of the Agrifood sector, a USD$7.8 trillion industry, responsible for feeding the planet and employing well over 40% of the global population. The pace of innovation has not kept up with other global industries and today agriculture remains the least digitised of all major industries…"

AgFunder reported that in 2017 alone, over USD$10bn was invested in AgriFood Tech in projects such as farm robotics and equipment, farm management software, agribusiness markets, online restaurants and novel home cooking platforms [AgFunder, 2017].

High profile acquisitions such as the USD$305million purchase of robotics start up BlueRiver Technology by John Deere Co, or farm management software start up Granular by DowDuPont for USD$300million, are signs the AgTech industry is maturing [AgFunder, 2017].

So, why are most farmers still only reading about these innovations that will transform their businesses, and when will they see some of this USD$10bn begin to filter down to the farm gate and make a positive change to the hip pockets?

Drawing from visits to 13 countries, and interviews with some of the world's most innovative farmers and prominent AgTech companies, this report provides a practical distillation of existing and near future technologies that will make a difference to farming practices, with a focus on orchard production. The report presents authentic case studies visited by the author, outlining commercial farming businesses that have embraced cutting-edge technology and are realizing the benefits. It aims to identify real risks to current business models identified through discussions with farmers from all over the globe, offering an in-depth analysis of current global trends such as urbanisation, increasingly unpopular temporary worker schemes and the seemingly limitless increases in workforce administration and regulatory costs. Whilst still maintaining a farmer first approach, the report presents near future technologies that are transitioning out of research and into development, aiming to address the most critical of these challenges.

The most common impediments to the adoption of these technologies have been established from interviews with visionary AgTech innovators and offer evidence to reconsider the real importance of these barriers whilst offering recommendations to the three critical stakeholders; farmers, industry and government.

The importance of maintaining the viability of Australian horticulture cannot be understated. Contributing AUD$2.23bn to the Australian total export value of fresh produce [Hort Innovation 2017], and responsible for the second largest category of rural employment, horticulture is critical to rural economies.

As the world continues to rapidly change and farm productivity growth has all but stagnated, farmers must look outside the box for new innovations, from new industries, for solutions.

"The electric light did not come from the continuous improvement of candles" (Oren Harari).

Figure 1: The author at home on his Mareeba property

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Foreword

I have had a non-traditional pathway into agriculture. Whilst my family have been farming for generations, when it came time to finish school, I chose a university pathway. It is said farming is in your blood, so after many years of living in Brisbane, marrying a dairy farmer's daughter and beginning a family, the urge became too great and I was presented an opportunity to manage an orchard "Blue Sky Produce" in Mareeba, Far North Queensland in 2013.

I was already the type of person to challenge the norm. Entering horticulture at the age of 33, after a successful non-agricultural career in management, afforded me a unique perspective. I became frustrated with tasks that I knew technology could solve. I implemented small technology changes, but it was the big issues around labour, harvesting and the accurate, efficient application of many farm inputs that I could not find a solution for and until federal budget night, May 2015, the need was not greater the effort.

Then Treasurer, the Hon Joe Hockey MP, announced on budget night, a plan to tax every working holiday visa holder 32.5% on every dollar they earned. By this time, I had survived my first two harvest seasons at Blue Sky Produce and it was clear that without Working Holiday Visas (WHV) holders, our business was not viable.

Proposed changes in July 2018 to the Horticulture Award 2010 approved by the Fair Work Commission (FWC) require growers to pay casual employee's overtime for every hour worked between 6pm-6am Monday to Friday, and Saturday (by agreement) and on Sundays [Fair Work Commission, 2018].

I turned to Google to find mechanised solutions to our heavy reliance on manual labour. I found a seemingly endless list of technological solutions to all our problems, but I could not find a single on-farm commercial application of any of the technology I was reading about. Why?

I embarked on a mission to find out why this promising technology providing a real solution, to real needs, was not being implemented.

My goal is for this report not to be another 'dreamer' piece on theoretical future technology that may or may not ever eventuate. The primary objective of this report is to highlight working technology that is available today, or very soon, that addresses real, on farm, needs.

Over the past two years, my scholarship has allowed me to travel to Brazil, Singapore, India, Qatar, Denmark, UK, USA, New Zealand, Egypt, Israel, The Netherlands, Germany and Indonesia and meet with the pioneers of the emerging "AgTech" industry, combining agriculture and technology. I have shared a coffee, a beer or a burrito with some of the most innovative farmers in the world.

This report captures the visions of these pioneers, their achievements and what farmers need to be aware of to prepare for and adopt the technology being developed.

"Resisting change is like trying to hold one's breath, even if successful, the result is undesirable" LaoTzu Chinese Philosopher 4th Century BC.

Acknowledgments

I am forever thankful to my wife Jess, who originally encouraged me to apply. I am sure there have been times she regretted this, at home with four young kids, the farm and her own growing business. I honestly do not know how you do what you do Jess. You are my inspiration to be better, every day. My children Jack, Toby, Lexi and Kipp, you have all had to step up and meet the challenges not having dad around presented, I am very proud of you all.

I would like to thank my employers, Ross and Shirley Johnson (my uncle and grandmother) and my farmhand Charlie Hobbins. Thank you for believing in me and trusting me to ensure your business was still well managed during my travels.

I would also like to thank my extended family. The awarding of a Nuffield Scholarship draws upon a wide net of support, from day time babysitting to Friday night fish and chips and Saturday sports logistics to the unexpected casserole dinner drop off. Thank you for supporting Jess during my travels.

Thank you to all who took time from your busy lives to meet with me. There were plenty of scheduled 20-minute meetings that turned into hours of truly engaging, challenging and thought-provoking discussions, over $2 tacos or a $200 bottle of wine. I feel privileged to have met every one of you. This report would not exist without the generosity of close to 100 people who took the time to speak with me.

Thank you to the Nuffield cohort of 2017 and broader alumni network who endured my dogmatic rants about technology, challenged the holes in my knowledge and opinions and (not so) gently directed my energy and passions.

Finally, thank-you to my investor Woolworths, and obviously the Nuffield Foundation, without these two very special organisations, these opportunities simply would not exist. I hope I have been, and continue to be, a good investment of your time and money.

Abbreviations

ABARES – Australian Bureau of Agriculture and Resources Economic Sciences

ACFR - Australian Centre for Field Robotics

AMIA - Australian Mango Industry Association

AWU - Australian Workers Union

FAO – Food and Agriculture Organisation

FFR – Fresh Fruit Robotics Israel

FWC - Fair Work Commission (Australia)

IFAD - International Fund for Agricultural Development

NUW - National Union of Workers

OECD - Organisation for Economic Co-operation and Development

PTO – Power Take Off

RAAT - Robotic and Agricultural Automation Technologies

ROI – Return on Investment

TIC – Thailand – Israel Employment Co-Operation

CQU – Central Queensland University

WUR – Wageningen University and Research

WHV – Working Holiday Visa (Australia)

Objectives

The overarching key objective of this report is to present a practical and realistic 'farmer first' overview of technology. Technology is bringing change at a pace that is difficult to keep up with. This poses considerable challenges to the status quo of agricultural production methods. For example, the 'social licence' and 'right to farm' is being challenged with the rise of 'camera in your pocket' agri-activism. New start-up BioTech firms are challenging the notion of what food even is by investing billions of dollars into alternate protein and energy sources such as cultured meats or sugar 'farmed' by E-Coli ['The Kitchen' Start-up incubator, Israel, 2018]. Increasing urbanisation trends are changing diets and putting more pressure on traditional supply chains, whilst distribution methods are being challenged on 'food miles' and food waste. Technology is rapidly shifting economic wealth as the fourth industrial revolution moves physical industries towards virtual products where teenagers can become billionaires developing apps from college dorm rooms. For example, only two of the top 15 startups over the past five years, with valuations over USD$1bn, deal in physical goods. Agriculture will always be subject to supply chain inefficiencies of moving physical product over large distances

The objectives include:

- Outline the current production systems across tree fruit production in Australia.
- Identify current and future trends that threaten existing production systems.
- Describe existing and near future technologies that will revolutionise how to farm.
- Identify impediments to the adoption of these technologies.
- Recommend how to facilitate the adoption of sound beneficial technologies and prepare for these changes today.

Chapter 1: Introduction

In the 2016-2017 period, Australian horticulture, with a total production of almost 6.5 million tonnes, was valued at close to AUD$13 billion [Hort Innovation, 2017].

Year Ending June 2017	Production (t)
All Horticultural Products	6,337,978
All Fruit	2,649,093
Apples	319,686
Avocados	65,992
Bananas	413,660
Berries - Combined	106,582
Blueberries	9,553
Rubus Berries	5,946
Strawberries	91,083
Cherries	11,012
Citrus - Combined	708,121
Grapefruit	12,647
Lemons/Limes	41,436
Mandarins	147,648
Oranges	506,391
Custard Apples	1,764
Kiwifruit	9,791
Lychees	2,419
Mangoes	61,474
Melons - Combined	231,146
Muskmelons	67,020
Watermelons	164,126
Nashi	3,000

Year Ending June 2017	Production (t)
Passionfruit	5,004
Papaya/Pawpaw	18,381
Persimmons	2,516
Pears	108,065
Pineapples	77,482
Summerfruit - Combined	126,177
Apricots	7,163
Nectarines/Peaches	92,017
Plums	26,997
Table Grapes	171,637
Processing Fruit Combined*	261,639
Dried Grapes	67,500
Prunes*	12,500
Other Dried Tree Fruit*	1,528
Canned Fruit*	50,111
Olives	130,000
Other Fruit	*7,686*
All Vegetables	3,502,673
Artichokes	374
Asparagus	8,033
Beans	29,039
Beetroot	14,053
Broccoli/Baby Broccoli	75,231

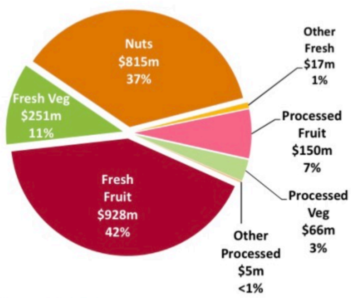
Year Ending June 2017	Production ($m)
All Horticultural Products	$12,910.0
All Fruit	$4,859.5
Apples	$497.2
Avocados	$374.5
Bananas	$514.4
Berries - Combined	$866.6
Blueberries	$193.6
Rubus Berries	$166.5
Strawberries	$506.5
Cherries	$120.7
Citrus - Combined	$724.2
Grapefruit	$17.4
Lemons/Limes	$105.2
Mandarins	$268.1
Oranges	$333.5
Custard Apples	$7.1
Kiwifruit	$20.4
Lychees	$26.7
Mangoes	$195.7
Melons - Combined	$172.4
Muskmelons	$76.1
Watermelons	$96.4
Nashi	$8.9

Year Ending June 2017	Production ($m)
Passionfruit	$19.0
Papaya/Pawpaw	$31.6
Persimmons	$10.5
Pears	$122.9
Pineapples	$54.2
Summerfruit - Combined	$386.1
Apricots	$29.9
Nectarines/Peaches	$281.4
Plums	$74.8
Table Grapes	$534.4
Processing Fruit Combined*	$177.4
Dried Grapes	$27.0
Prunes*	$8.4
Other Dried Tree Fruit*	$0.5
Canned Fruit*	$16.3
Olives	$125.1
Other Fruit	*$19.6*
All Vegetables	$4,291.6
Artichokes	$0.9
Asparagus	$52.9
Beans	$77.8
Beetroot	$10.7
Broccoli/Baby Broccoli	$228.6

Figure 2: Horticulture contributed AUD$2.23 billion toward Australia's total fresh produce exports of AUD$44.8 billion [Source: Hort Innovation, 2018]

Total Exports

For the year ending June 2017, Australia exported **$2.23 billion** worth of horticultural products. Fresh Fruit was the largest value export grouping. The value of exports by group is profiled in the chart and table below. The table below also includes the top 3 export categories within each group. *These values do not include wine grapes.*



Sources: GTA; (Freshlogic Analysis)

Fresh Fruit	**$927.7m**	**Other Fresh Horticulture**	**$16.9m**
Table Grapes	$372.6m	Cut Flowers	$9.7m
Oranges	$223.7m	Live Plants	$6.9m
Mandarins	$78.7m	Bulbs	$0.2m
Fresh Vegetables	**$250.6m**	**Processed Fruit**	**$149.7m**
Carrots	$90.7m	Dried Grapes and Grape Juice	$37.0m
Asparagus	$30.9m	Olives and Olive Oil	$23.6m
Potatoes	$27.8m	Orange Juice	$7.9m
Nuts	**$815.3m**	**Processed Vegetables**	**$65.6m**
Almonds	$461.2m	Tomatoes	$20.9m
Macadamias	$291.0m	Potatoes	$16.8m
Walnuts	$15.9m	Cabbage	$5.5m

Figure 3: Total 2017 horticultural exports by major crop [Source: Horticulture Innovation 2018]

Horticulture is recognised to be critically important to the ongoing prosperity of rural communities, being the second largest agricultural industry employer in Australia, with approximately 62,300 people employed in 2016/2017, second only behind the combined category of sheep/beef/grains [Australian Government Department of Agriculture, 2013].

Persons employed in agriculture, forestry and fisheries **ab**

	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10
	'000	'000	'000	'000	'000	'000	'000
Horticulture **c**	98.1	86.2	82.7	83.3	76.5	60.5	57.7
Sheep, beef cattle and grain	165	138	137	132	136	151	144
Other crop growing	8.5	11.2	7.9	10.6	10.9	14.9	12.5
Dairy cattle	19.4	21.8	22.5	17.3	23.0	26.8	23.3
Poultry	10.8	9.9	8.4	8.6	6.5	8.1	8.6
Other livestock **d**	11.1	9.0	10.9	10.9	8.7	12.6	15.3
Other agriculture **nfd**	7.3	31.6	31.8	35.9	30.0	36.9	42.7
Total agriculture	320	308	301	299	292	310	304
Forestry and logging	8.6	8.4	8.8	8.2	7.2	8.3	6.8
Forestry support services	3.0	2.9	3.0	3.2	3.4	3.7	3.4
Aquaculture	5.5	5.5	4.0	3.1	4.3	4.3	4.0
Fishing	9.3	5.3	6.3	4.0	5.1	3.1	4.0
Other agriculture, forestry and fishing	0.9	3.2	1.3	1.5	1.2	1.2	2.1
Hunting and trapping	0.5	0	0.4	0.4	0.5	0.8	0.9
Fishing hunting and trapping **nfd**	2.5	2.2	1.8	2.0	3.0	1.9	1.1
Agriculture and fishing support services **e**	20.4	20.7	23.2	22.0	21.9	20.2	19.6
Total agriculture, forestry and fishing	371	356	350	343	338	354	346
	2010–11	**2011–12**	**2012–13**	**2013–14**	**2014–15**	**2015–16**	**2016–17**
	'000	'000	'000	'000	'000	'000	'000
Horticulture **c**	60.2	57.0	58.0	62.6	51.8	63.6	62.3
Sheep, beef cattle and grain	137	125	116	101	123	91.9	92.9
Other crop growing	10.6	8.5	13.0	9.4	4.0	4.0	4.2
Dairy cattle	27.3	23.5	20.9	25.9	21.4	26.1	27.0
Poultry	8.5	9.6	10.4	4.6	5.4	11.5	10.3
Other livestock **d**	13.3	9.9	11.0	9.6	15.3	14.0	9.3
Other agriculture **nfd**	46.0	39.3	41.5	50.4	60.8	62.2	54.7
Total agriculture	303	273	271	263	282	273	262
Forestry and logging	5.8	6.9	7.5	5.6	6.0	5.5	7.4
Forestry support services	3.2	3.7	3.0	3.1	2.9	2.6	4.9
Aquaculture	4.7	4.0	2.5	4.6	7.5	5.0	7.9
Fishing	5.8	5.1	5.2	3.8	5.1	5.2	6.3
Other agriculture, forestry and fishing	2.8	1.7	2.6	2.2	2.5	1.6	1.6
Hunting and trapping	1.6	0.4	0.3	0.2	1.0	0.2	0.3
Fishing hunting and trapping **nfd**	1.1	1.0	0.9	0.1	0.4	0.3	0.7
Other agriculture, forestry and fishing	19.2	19.3	19.2	21.4	18.0	17.8	19.2
Total agriculture, forestry and fishing	347	316	311	304	325	312	310

a Average employment over four quarters. **b** ANZSIC 2006 **c** Includes nursery, floriculture, vegetable, fruit and tree nut growing. **d** Includes deer farming. e Includes agriculture, forestry and fishing support services not further defined.

Note: ABS advises caution should be used when using employment statistics at the ANZSIC subdivision and group levels due to estimates that may be subject to sampling variability and standard errors too high for most practical purposes.

Sources: Australian Bureau of Statistics (ABS), *Labour Force, Australia, Detailed - Electronic Delivery*, cat. no. 6291.0.55.001, Canberra; ABS, *Labour Force, Australia, Detailed Electronic Delivery*, cat. no. 6291.0.55.003, Canberra

Figure 4: Persons employed in agriculture, forestry and fisheries [Source: ABARES Agricultural commodity statistics 2017]

It is perhaps this reliance on staff that presents the greatest future risk to the horticulture industry. ABARES reported in its Labor Force Survey 2016, lower farm business profits and the availability of quality labor as the greatest workforce challenges facing farm business over the next five years [ABARES, 2017]. Over one third of total horticultural costs are labour [ABARES, 2017].

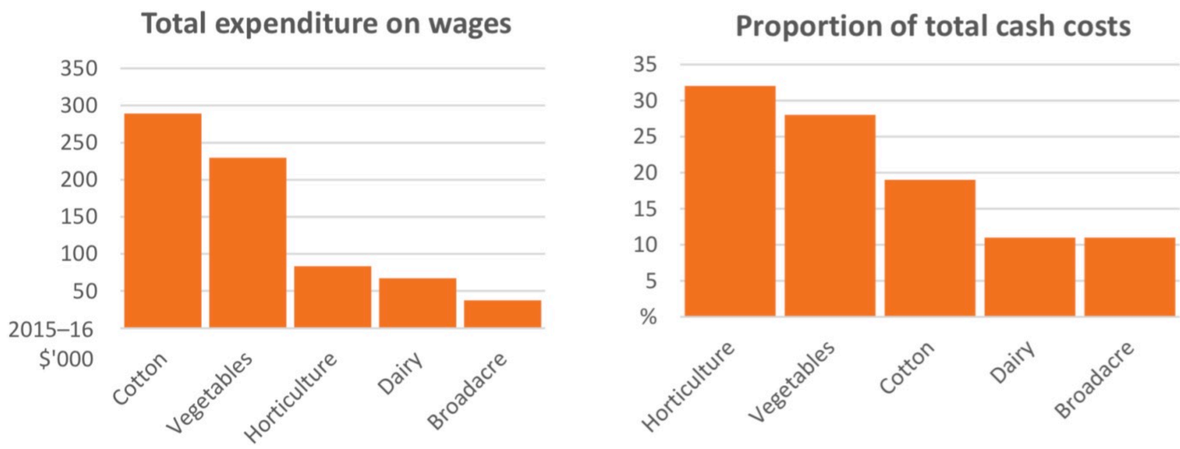


Figure 5: Total expenditure on wages versus proportion of total cash costs per industry [Source: ABARES Labour force survey, 2016]

For many individual horticultural crops, the labour costs are even higher. Figure 6 below illustrates the difference between the total labour expenditure relative to the level of mechanization. As an example, there is significant difference between potatoes (mechanised harvest) vs asparagus (manual harvest) [ABARES, 2017].

Estimated amount and expenditure on labour per hectare, by selected vegetable crops, New South Wales, 2013

Vegetable	Total labour expenditure ($)
Sweet corn	309
Potatoes (processing)	748
Carrots (processing)	900
Beetroot (processing)	1,320
Butternut pumpkin	3,787
Lettuce	4,045
Capsicum	5,871
Garlic	8,098
Onions	8,749
Asparagus	14,113

Note: Expenditure is in 2013 dollars. Estimates will differ across farms depending on their natural resource endowments and production processes. Refer to the primary source for assumptions and wage rates.
Source: NSWDPI 2013

Figure 6: Estimated amount of expenditure on labour per ha, by selected vegetable crops, NSW 2013 [Source: ABARES Labour force survey 2016]

Australia’s Working Holiday Visa (WHV) scheme introduced in 1975, is critical to the supply of this temporary labour force. Figure 7 shows both horticulture and vegetable production rely on almost 70% WHV holders for its seasonal workforce, and over 60% of all employees in horticulture are seasonal [ABARES, 2017].

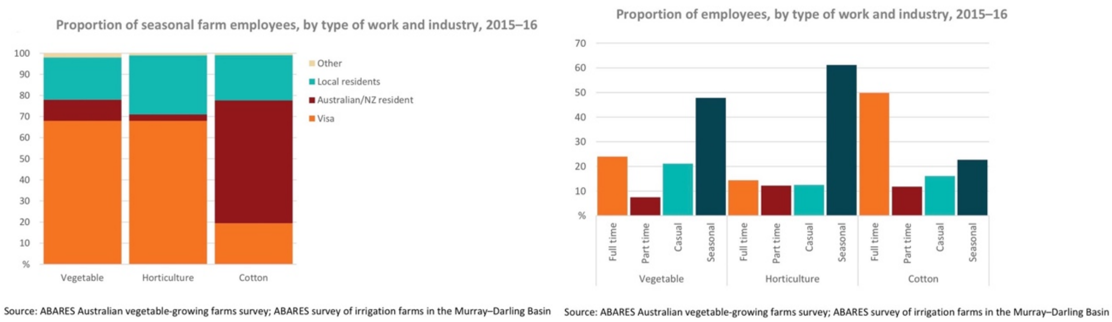


Figure 7: Proportion of seasonal workers by type (visa/local) and employment (full time/casual) [Source: ABARES Labour forces survey 2016]

Agriculture has been the greatest beneficiary to the scheme which grants a second-year extension to the visa holder if they complete 88 days of "specified work" in either agriculture, mining or construction, with 95% of second year visa applicants completing their 88 days in agriculture [Australian Government Department of Immigration and Boarder Protection, 2017].

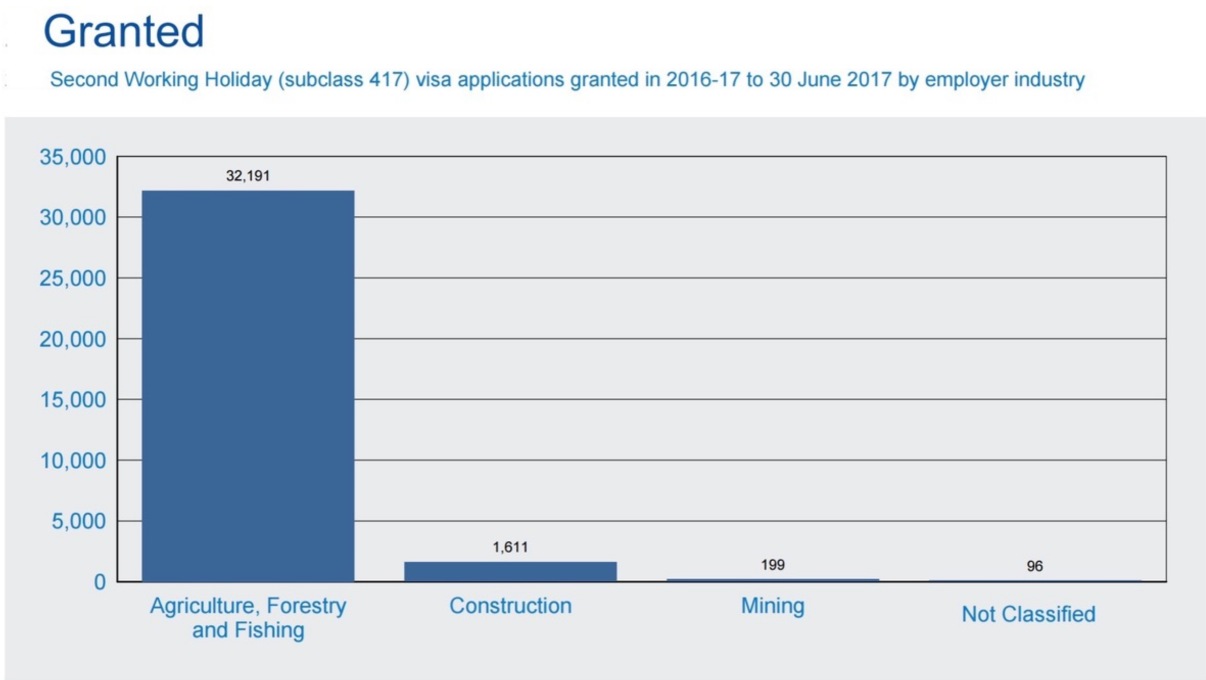


Figure 8: Number of successful second year visa applications by industry [Source: Working holiday maker visa report 2017, Australian Government Department of Immigration and Border Protection]

Due to the seasonal, and perishable nature of fresh fruit, price returns are highly susceptible to over (and under) supply variations that are determined by supply and demand markets, yet there is little adoption of rigorous forecasting models to plan and prepare the supply chain for incoming supply. Production practices in many tree fruit systems are still based on traditionally low-density planting models. For example, the average mango planting density in Australia is between 100-200t/Ha [Menzel, 2016] achieving average production yields of 5-14t/Ha [NT Government, 2002].

Figure 9: Typical Australian mango planting, 8m x 7m, 180 trees/Ha [Source: Author]

Australian Avocado orchards have an average planting density between 170-300t/ha, achieving on average 7t/Ha [Whiley, A. 2012]

Figure 10: Typical Australian Avocado planting, 7m x 6m, 240 trees/Ha [Source: Author]

Chapter 2: Challenges to Current Systems

Temporary Worker Schemes

Australia's horticulture industries reliance on the WHV Scheme cannot be understated. During the "Backpacker Tax" political debate, farmers were left with fruit rotting in the paddocks [ABC, 2016].

An Australian Government Department of Immigration and Border Protection report into the WHV Scheme from 1 January 2015 – 30 June 2017 shows just how detrimental the protracted and very public “backpacker tax” debate has been. There was a total reduction in applications of 10,663 in this period. Importantly though, prior to the backpacker tax, there was a steady application of second year extensions of approximately 20,000 which has now dropped by over 20% [Australian Government, 2017].

Total number of Working Holiday Maker visa applications granted in the 6 month period ending 30 June 2017 by visa subclass and visa type - comparison with previous four periods

Visa Subclass	01/01/15 to 30/06/15	01/07/15 to 31/12/15	01/01/16 to 30/06/16	01/07/16 to 31/12/16	01/01/17 to 30/06/17
417 Working Holiday					
First visa	81,117	86,847	72,562	85,641	72,217
Second visa	18,906	19,320	16,944	17,477	16,620
All 417 Working Holiday	**100,023**	**106,167**	**89,506**	**103,118**	**88,837**
462 Work and Holiday					
First visa	6,103	10,583	8,327	12,219	6,428
Second visa	0	0	0	0	409
All 462 Work and Holiday	**6,103**	**10,583**	**8,327**	**12,219**	**6,837**
All Working Holiday Maker	**106,126**	**116,750**	**97,833**	**115,337**	**95,674**

Figure 11: Number of Working Holiday Maker visa applications 01/01/15 to 30/06/17 [Source: Working Holiday Maker visa report 2017. Australian Government Department of Immigration and Boarder Protection]

Temporary worker schemes have been the go-to labour solution for high wage nations for decades. They have worked well throughout the world. Programs such as the Thailand - Israel Employment Co-Operation (TIC) five year worker scheme, the Canadian Temporary Foreign Worker Program, the Kafala system in the Saudi Gulf Emirates, along with Australia’s WHV Scheme, have filled work force supply gaps well, but as was tested in Australia with the Backpacker Tax, and the now defunct Seasonal Agricultural Worker Scheme (SAWS) in the UK, these solutions are highly volatile political policies and any political solution is subject to popular support. As we have seen in recent years, these schemes have come under heavy human rights scrutiny and objections.

International media coverage of Thai workers dying from what Israeli authorities identify as "Sudden Nocturnal Death Syndrome" threatens the viability of the Israeli agricultural work force [Human Right Watch, 2014, 2015, 2016]. The Saudi's Kafala system has been widely criticised for human rights abuse of Indian, Pakistani and Indonesian construction and domestic workers [HRW, 2018]. In the UK, a suitable replacement to the SAWS has been in limbo since 2013 as there has not been a bipartisan political agreement due to its unpopularity with the voting public. Brexit now brings more uncertainty to the availability of temporary workforce for British farmers [The Guardian, 2017]. In Australia. following the tragic murder of two backpackers by a French backpacker in a North Queensland Hostel, the WHV scheme has come under public scrutiny and has even been directly blamed for these unfortunate deaths [Ayliffe, R. 2017].

Without the continuation of migration policies that allow temporary labour to flow into, and out of, high-income countries, the supply of manual agricultural labour forces are at risk.

Urbanisation

Added to the temporary worker program issues, there is a global urbanisation challenge drawing more people out of rural areas. A 2016 report by the FAO on 'The future of food and agriculture, Trends and challenges' states:

"For decades, the world's population was predominantly rural. Thirty-five years ago, more than 60 percent of all people lived in rural areas. Since then, the urban-rural balance has changed markedly, and today slightly more than half of the global population (54 percent) is urban. Thirty-five years from now, in 2050, more than two-thirds of all people may be living in urban areas."

The report goes on to highlight:

"… at the same time, agriculture, food and nutrition have been, and are likely to continue be, affected by the changes brought about by urbanization."

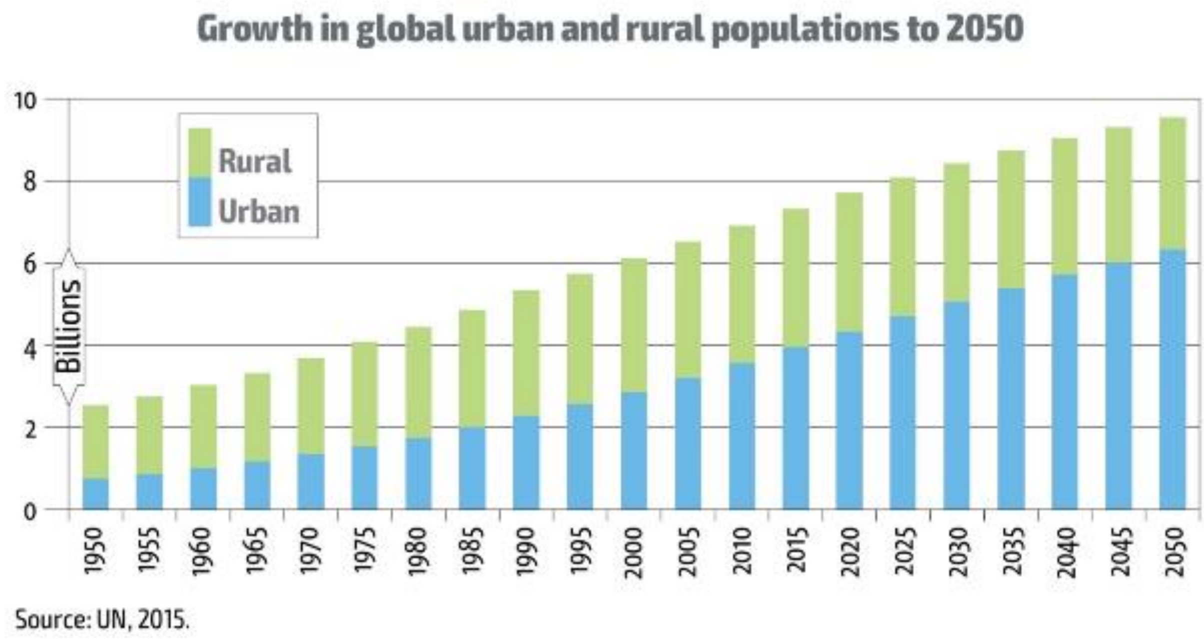


Figure 12: Trending growth in global urban versus rural populations. [Source: FAO Food and Agriculture Trends and Challenges 2017]

The report states that by 2050, rural populations may see a net reduction of 200 billion people, all while the urban population, demanding more centralised consumption of food, increases [FAO, 2016].

Agriculture has historically been the primary employer in rural communities, but urbanisation has had a significant effect on the amount of the population employed in agriculture. As reported by the World Bank, using data compiled from ILOSTAT, employment in agriculture as a percentage of total global employment has dropped from just under half of the world employed in agriculture to approximately a quarter, since 1991 [World Bank, 2017].

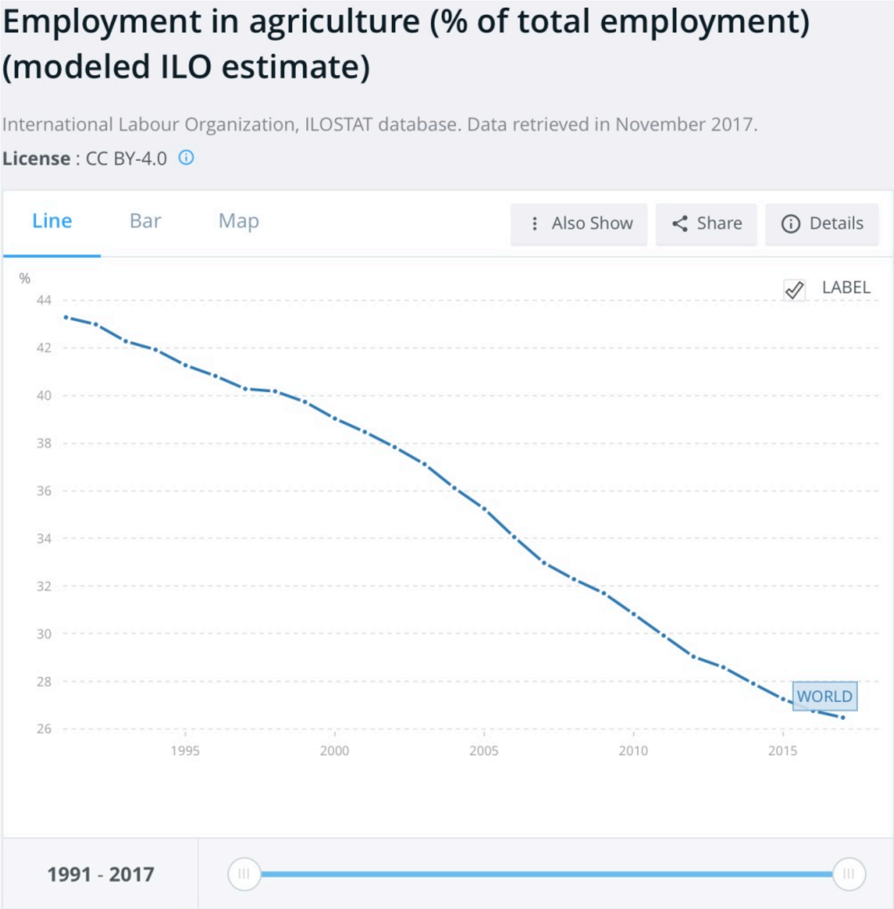


Figure 13: Down-trending global employment in agriculture [Source: World Bank, 2017]

Perhaps the most worrying trend forming in urbanisation statistics is that while urbanisation up until the 1970's was a high-income nation trend [FAO, 2016], rapid economic growth in low income nations are now showing greater rates of urbanisation then their rich cousins. Traditionally, it is often the lower income countries from where agriculture has relied on to fill labour supply gaps through entering a high-income country without any necessary skills to better their financial position at home. FAO and World Bank refer to this practice as "Transnational Remittances". According to World Bank Data, remittances have increased from about USD$30 million globally in the 1990's to an estimated USD$317 billion in 2007. 75% of this is directed to middle-low and low-low income nations [FAO/IFAD, 2008].

Remittance flows to developing countries
(US$ billion)

	2002	2003	2004	2005	2006	2007	Change 2006-2007 (%)	Change 2002-2007 (%)
East Asia and the Pacific	29	35	39	47	53	58	10	97
Europe and Central Asia	14	17	21	29	35	39	10	175
Latin America and the Caribbean	28	35	41	49	57	60	6	115
Middle East and North Africa	15	20	23	24	27	28	7	86
South Asia	24	30	29	33	40	44	10	81
Sub-Saharan Africa	5	6	8	9	10	11	5	116
Developing countries	116	144	161	191	221	240	8	107

Figure 14: International remittance flows to developing nations [Source: FAO International migration, remittances and rural development report, 2008]

As the economies of the lower income nations improve, and urban employment opportunities follow, the rise of low income urbanisation will continue to have considerable impact on the availability of immigrant labour.

Continued popularity of protectionism politics such as Brexit, the narrowly avoided "Frexit" (French exit from the EU), the newly elected and openly anti-immigrant Five Star Movement to the Italian Government and anti-immigration policy from the Trump administration creates an enormous impending challenge to immigrant labour. Only days before the completion of this report, the new EU Migration deal, seeking to put an end to "secondary EU migration", was passed, implementing considerably stronger controls on refugee and immigration into and between EU borders. German Chancellor Angela Merkel has gone as far to say: *"(that) migration could decide the fate of the EU"* [The Guardian, 2018].

Rising cost of labour

As the labour market is challenged with supply, the cost of labour rises. Recognising reducing supply and increasing cost of labour in the EU, Geopa-Copa of the Employer's Group of Professional Agricultural Organisation in the European Union, commissioned a report into labour costs in European agriculture. The report found that in a six-year period from 2006 –

2012, labour costs in many European countries had doubled. In the case of Hungary, considered in 2006 to be a low-income country, agricultural hourly wages had risen by more than 250% to retain local agricultural workers [Geopa-Copa, 2013]. In turn, as the low-income economies subsequently improve, the need to migrate reduces, so higher income countries have to react by raising base wages to continue the attractiveness of migration and maintain their non-skilled labour force.

Euros per hour worked by a permanent member of staff

	2012	2006
Denmark	28.37	18.88
Sweden	23.77	15.80
United Kingdom	22.16	10.26
Finland	21.58	12.31
Austria	16.63	13.32
France	16.61	10.61
Netherlands	15.73	12.42
Belgium	15.19	12.30
Italy	13.72	11.15
Ireland	11.22	7.28
Spain	9.38	8.50
Hungary	5.28	2.02
Portugal	4.35	4.33
Latvia	3.90	1.22
Poland	3.32	1.85
Lithuania	3.13	2.36

Figure 15: Euros/hour wage increases 2006-2012 [Source: Employment in European Agriculture: Labour costs, flexibility and contractual aspects. Geopa-Copa Statistical research institute with financial support from the EU, 2013]

The same report shows that it is not only the per hour wage that is increasing but the 'additional staffing costs' such as sick and holiday pay, overtime and penalty pay, employer social security contributions and training costs that now make up to 107% of the total employee received payment. One example of this is in Spain. See Figure 16.

Permanent Employees in Agriculture in 2012

	Total Labour Costs	Direct Pay	Additional Staffing Costs
	In euros for every hour worked		As a percentage of the direct pay
Denmark	28.37	20.15	41
Sweden	23.77	14.55	63
United Kingdom	22.16	15.05	47
Finland	21.58	11.47	88
Austria	16.63	8.71	91
France	16.61	9.43	76
Netherlands	15.73	9.42	67
Belgium	15.19	10.08	51
Italy	13.72	8.06	70
Ireland	11.22	9.10	23
Spain	9.38	4.54	107
Hungary	5.28	3.14	68
Portugal	4.35	3.00	45
Latvia	3.90	2.65	47
Poland	3.32	2.48	34
Lithuania	3.13	2.09	50

Direct pay: Remuneration for hours actually worked (Gross earnings excluding special payments minus remuneration for work-free time such as holiday or national holidays);
Additional staffing costs: Labour costs minus direct pay. Components of the additional staffing costs include remuneration for time off work (holiday, sick days as long as the employer agrees to continue to pay the wages, and special payments for time off work), special payments (for example Christmas and holiday pay, performance-related pay and bonuses), the employer's social security contributions, expenses related to taking part in the company pension scheme and of training and further training and miscellaneous costs such as severance pay and participation in company structures.

Figure 16: Percentage of total remuneration in "additional staffing costs" versus actual hours worked [Source: Employment in European Agriculture: Labour costs, flexibility and contractual aspects. Geopa-Copa statistical research institute with support from the EU, 2013]

'Additional staffing costs' are also increasing in Australia. Mechanised solutions have had great success at alleviating this pressure.

Food safety and traceability

Recent food safety incidents such as the listeria outbreak in Australian rockmelons and Hepatitis A in imported frozen berries [Food Safety Standards Australia/NZ, 2018] have increased pressure on regulation and called for complete paddock-to-plate traceability. The rockmelon listeria outbreak had catastrophic financial impact on the Rombola family business, but also caused the demand for Australian rockmelons to drop by up to 90%, effecting every rockmelon grower in the country, as well as Australia's export markets [ABC, 2018]. Increased food safety and track and trace administrative burdens are proving too much for some smaller family farms, causing some to consider the viability of their business [ABC, 2018].

Chapter 3: Technology Available Today

Case Study 1: Precision Makers, Verkooijen Fruits, The Netherlands

Precision Makers is a new company developed out of Conver, a machinery manufacturer developing solutions to maintain the "Green Zones" throughout The Netherlands. Green zones include dykes and canals which have unique access challenges. It is from this long heritage of developing highly specialised machines for unique problems, that the idea for Precision Makers was born.

Figure 17: GreenBot, Precision Makers, NL, Standard 3-point lift, PTO, hydraulic remotes and GreenBot manual control centre, also controllable via the cloud [Source: Author]

Orchard farmers have a number of time-consuming tasks, such as spraying and mowing that will benefit from the precise repeatability of robotics. Semi-skilled workers capable of operating machinery, able to work safely with chemicals, and content to often work throughout the night are hard to come by so the team at Conver created the GreenBot, a fully autonomous, 110HP vehicle with the vision it would one day replace the common tractor.

Allard Martinet, Business Development Director, advised their greatest challenge was competing with the far more versatile and ubiquitous tractor platform. The GreenBot was going to cost what a mid-range tractor would, but only able to perform specialised tasks. To address this, they adapted the technology contained within the GreenBot, so it could be retrofitted to a standard tractor. The first customer was John Verkooijen of Verkooijen Fruits, Waalwijk, The Netherlands. Verkooijen Fruits has been growing apples and pears since the 1950's across 58Ha and has increased production and installed cold room facilities capable of holding over 3,500 tonne.

Precision Makers installed its autonomous system three years ago into Mr. Verkooijens Fendt 208V, which was his full-time spray tractor. Mr. Verkooijens was willing to accept a ten-year return on investment (ROI) as a trial, requiring the tractor to perform approximately 200hrs/year. His spray program was approximately 700 hours/year. Since then, the tractor has averaged 1,000 hours/year, or approximately three hours/day, able to perform the entire spray program on its own, and now also incorporating the mowing program. Mr. Verkooijen's ROI was reduced to three years.

Verkooijen Fruits' Fendt 208V spray tractor fitted with Precision Makers Autonomous System

The 'smart box' required on the sprayer to communicate with the in-cab control system.

In-cab control system and navigation map.

"Driving" the Fendt, no hands.

Figure 18: Verkooijen Fruits' Fendt 208V spray tractor [Source: Author]

Mr. Verkooijens revealed some interesting results and insights. Human operator spraying was difficult to achieve at the most effective time, at night, due to regulatory compliance with staff working hours. So, for convenience the spraying was often completed during the day. Now all spraying is done at night. He has also reduced driving speed (due to no consideration for staff hours) and recalibrated nozzles to achieve a reduction in chemical usage of over 20%. He has also seen an increase in marketable fruit he is attributing to the more regular, effective and repeatable spray program.

Human operator mowing was completed at 10km/hour, consuming 10L of fuel/Ha, and was also ‘hard’ on the machinery. The robotic mowing is now achieved at 5km/hour consuming 4L of fuel/Ha, resulting in a better cut, and reducing the wear and tear on the machine.

Uncomplicated ultrasonic radar for collision detection

Front bar sensor will activate the emergency stop if the hinged bar makes contact with something and is pushed back

Figure 19: Verkooijen Fruits’ Fendt 208V spray tractor (Cont’d) [Source: Author]

Mr. Verkooijens identified the greatest advantage to retro-fitting his Fendt with the Precision Maker system was *“(that) time is no longer a problem. The spraying occurs precisely when it most effective, with no consideration for industrial relations or staff compliance. The staff are happier not handling dangerous chemicals, and they have been freed up for tasks that help me improve the farm even more.*” [Verkooijens, J. 2018]

Case Study 2: Taylor Farms, Salinas Valley, California

Taylor Farms is the largest processor of ready to eat cut salad product in the world. The business employs over 10,000 people across 14 processing factories, the largest plant being in Salinas. Taylor Farms partners with hundreds of growers and produces over a third of the lettuce consumed in the USA [Offerdahl, D. 2017].

Prior to meeting Bruce Taylor at the Forbes AgTech Summit 2017, the author believed the greatest challenge with labour was the rising costs and administration of human workforces. Mr. Taylor explained a situation that had occurred only 12 months earlier that emphasised that labour supply was a far greater issue then labour cost.

Figure 20: Hand harvesting celery. The author saw hundreds of fields of up to 50 workers throughout Salinas Valley like this [Source: Author]

Mr. Taylor tells a story when his factory staff had staged a walk out, demanding USD$3/hour more pay. It settled at USD$1.50 which cost Taylor Farms hundreds of thousands of dollars in wages, but it cost him millions in lost production for that one day.

What Mr. Taylor realised was that while the number of foreign workers willing and available to do the work reduced, the balance of power had shifted, and the workers had the upper hand.

Bruce Taylor was witnessing this situation in the fields also. It was becoming more difficult to employ the required number of workers to complete harvest before spoilage, and some fields were being abandoned mid harvest.

A typical hand harvest of lettuce, or celery, is achieved by teams of up to 50 workers, bent over at 90 degrees working with sharp knifes cutting the crop at ground level and then stacking piles of produce on the dirt for a separate packing crew to come and load in boxes.

In discussion with Taylor Farms Head of Ag Engineering's David Offerdahl, the true benefits of a shift to mechanised harvesting became apparent. Today, the Taylor Farms mechanised harvester is capable of harvesting multiple crops and has been rolled out across the majority of Taylor Farms production partners.

This machine uses high pressure water jets to cut the crop at a precise (adjustable) level from the ground, reducing dirt collected or crop wasted by the variability of hand harvesting. It also removes the leafy tops leaving them in the field, reducing the volume of crop (waste) requiring transportation to the packing shed by approximately 20%. This also returns organic matter to the soil. The machine then 'grabs' the crop and elevates it to a platform where ten workers clean it (removing outer layers) and pack directly into boxes. All workers are working at a comfortable standing waist height, or even sitting down.

Figure 21: Leafy tops are removed at an exact height, then the crop is 'cut' from the ground using high pressure water, then 'grabbed between two rubber belts and elevated to the workers to clean and pack [Source: Author]

Figure 22: All workers are at a comfortable standing height. Ten workers can cover the same area as up to 50 'hand harvesters' [Source: Author]

Taylor Farms has calculated the business is saving approximately USD0.03c/kg on harvest labour alone. The largest (Salinas) factory processes 7.2 million kgs per week. The cost saving is significant, but as Bruce Taylor points out, perhaps even more importantly, he now has the most attractive farms to work on. He believes that even as the Trump administration's anti-immigration policy is putting unprecedented pressure on labour supply, if it came down to the last ten workers in California, they would choose his farms because he has made the work considerably more attractive.

During a field visit, the author spoke with one of the workers on the harvester, who explained that he had been hand harvesting in the Salinas Valley for 25 years, just as his father had done before him. He used to tell his sons to find other work because harvesting was the most difficult work imaginable. But now, he is encouraging his sons to join the Taylor Farms harvest team because it is "very easy good work" with the machines [Worker, Taylor Farms, name withheld, 2017].

Case Study 3: Kibbutzim Kfar Glikson, Nair Ezyon, Kfar Hammakkabi and Ayal, Israel

The Kibbutzim visits are a relevant case study, not because they are developing futuristic robotics, but because their farming methods, designed purely from an agronomic production improvement perspective, have inadvertently prepared them well for technology in development today. Their transition to the next wave of technology will be swift and low impact.

Every orchard visited in Israel used fully autonomous watering and fertigation systems as standard, and they did not see these systems as new or innovative. The notion of scheduled watering, or watering based on 'gut feel' and 'experience' was horrifying to them. The most sophisticated system observed used a network of water probes, weather stations, dendrometers and fruit growth sensors to fully autonomously initiate, and stop, watering, whilst simultaneously injecting liquid fertiliser at pre-determined ratios in every watering shift. Since adopting the 'every day feeding' system, Kibbutz Orchard Manager Ofri Youngerman, estimated the business had achieved a yield increase of approximately 10%, whilst simultaneously reducing the amount of total fertiliser required by 15%.

Wireless moisture probes with analog redundancy, Israel

Wireless 'dendrometer' measuring trunk diameter variations due to moisture stress, Israel

Wireless irrigation controller, Israel

Fruit growth sensor, Israel

Figure 23: Examples of common precision measuring tools used in Israel [Source: Author]

Elon, Orchard Manager of over 300Ha of avocados at Kfar Glikson, had calculated a water use reduction of over 60% since moving to a fully autonomous watering system.

"*Farmer Brain meant I 'felt' like the trees needed water when in fact, the measurements proved they did not, and too often, it was a feeling that I needed to be doing something to be 'working'. Now that the trees are being fed and watered autonomously based on scientific measurements, I am free to concentrate on jobs that get me forward every day"* [Elon, Kibbutz Kfar Glikson, 2018].

Necessity drives innovation, and after the three year "War over Water" from 1964-1967 with its Arab neighbours, Israel recognised they needed to become extremely efficient irrigators.

Modern day drip irrigation was first developed on a desert based Israeli Kibbutzim, Kibbutz Hatzerim in 1960-1965 in partnership with the inventor Simcha Blass. It was through this collaboration the company Netafim was formed. Today, over 80% of agricultural irrigation water in Israel is recycled effluent from the cities, and 40% of the cities' drinking water is desalinated. They are so committed to water efficiency, the Israeli Department of Water has made it illegal to use under tree micro sprinklers with recycled water, due to the cost of recycling it, virtually forcing irrigators to adopt drip systems [Gafni, U. 2018].

Whilst the 'more from less' adage has become popular in recent years, in Israel it has always been a core driving force and it is now ingrained in their agricultural culture. At Kibbutz Hammakkabi, Head Agronomist Doron revealed an on-farm rootstock trail block, with no industry or government support, of over 3,000 trees, evaluating low vigour suitability for high density planting systems.

Figure 24: On-Farm, 3000 Tree trial block evaluating rootstock suitability for high density planting, Israel [Source: Author]

Doron also presented his 3 x 3 planting, (1,110 trees/Ha) block targeting a yield of 40t/Ha. By comparison, the Israeli average is 6 x 3 (555 trees/Ha) with a yield average of 15t/Ha for the Hass cultivar [Gafni, U.2018]. Doron is expecting even more water savings using this system, as there will be greater light inception across the block, also reducing weed pressure.

It is in this 3 x 3 high density orchard, the greatest preparedness for the new technology was witnessed. Since trees will be maintained no higher than 1.6meters, with a width no greater then 80cms, this poses access issues for traditional tractors, and it is here where smaller, 'swarming' machinery will be used. This machinery is so small, there would not be room to accommodate a human operator.

Figure 25: 3m x 3m high density planting systems, 1,110 tree/Ha. 'Lamb Hass' cultivar, Israel [Source: Author]

Chapter 4:Technology Available Tomorrow

Of the major challenges with current production systems outlined above, the author identified three that technology could address.

1. Availability of engaged semi-skilled labour for repetitive machinery-based tasks spraying/slashing/boom weeding.
2. Inaccurate yield forecasting and harvest timing decision-making tools causing price volatility and low-quality fruit in the supply chain.
3. Harvesting by seasonal workers and the over reliance on WHV workforce.

Addressing the availability of semi-skilled labour

Precision Makers NL has an off-the-shelf solution available today for autonomous spraying, slashing and boom/weed spraying. It is an excellent solution, commendable for its simplicity which has been the reason the business has placed actual working systems in the hands of production orchardists today, rather than just distributing 'proof of concept' videos. Unfortunately, the system has one major caveat. It relies on the ability to communicate with the original tractor software, which, if updated by the manufacturer, can break the Precision Makers code requiring time consuming re-coding. The author likens the future of tractor software to current mobile phone software which may receive major updates monthly, rendering the idea of third-party retro fit solutions unviable. Tractor manufacturers must offer their own 'bolt on' solutions or adopt a symbiotic development platform akin to "Software Development Kits" (SDK's) used in the technology world to allow developers to design solutions that will officially be supported by the manufacturer software.

Addressing inaccurate yield forecasting and harvest decision tools

Machine Vision holds the promise of being able to scan trees and measure biomass, flower load, fruit setting, fruit sizing and eventually counting. Whilst many research institutions are working on this, with limited success, the Central Queensland University (CQU) Precision Ag machine vision engineers are leveraging deep learning techniques with promising results. Below is a summarised excerpt from the "Deep learning for real-time fruit detection and orchard yield estimation - benchmarking of mangoYOLO - 512' paper:

"…Common challenges for machine vision to detect and recognize fruits in real orchard scenes are varying illumination, occlusions, orientation of fruits and the special case of similar colour attributes of fruit and foliage. During the past decade there have been many reports of object classification in orchard scenes involving hand-crafted features such as intensity threshold, colour space, shape and texture features……. However, these approaches often fail to generalize to other conditions (cultivars, growing conditions, lighting conditions) without re-design. For example, applied colour based segmentation technique followed by blob detection to recognize mango fruits in orchard images placed emphasis on texture analysis to achieve an improved fruit detection rate. Similarly, detected mango fruit based on elliptical shape fitting and applied texture analysis to define the fruit edge, followed by morphological operations on binary image and ellipse fitting using Randomized Hough Transform (RHT) technique for detection of mango fruit in clusters. Detection errors were associated with leaves of similar shape to fruit and occluded fruits…."

Due to development successes in deep learning techniques in non-agricultural industries, CQU engineers have made relatively small adaptations to these techniques to leverage their momentum for the application of fruit detection. The results have been promising, in some instances the machine vision fruit count was within 10% of the pack house count [Walsh, KA, et al, 2018].

Number of fruits detected for each orchard using dual view imaging compared to the packhouse fruit count. Best result within a row is indicated in bold.

		Faster-RCNN-VGG-512		YOLOv3-512		modified-YOLO-512		mangoYOLO-512	
Block name	Packhouse Count total	total fruits detected	%err on total packhouse count	total fruits detected	%err on total packhouse count	total fruits detected	%err on total packhouse count	total fruits detected	%err on total packhouse count
A	97382	55506	-43.00	59300	-39.11	58074	-40.36	60342	**-38.04**
B	26273	15399	-41.39	16586	-36.87	16189	-38.38	16978	**-35.38**
C	40837	16983	-58.41	17822	-56.36	17329	-57.57	18283	**-55.23**
D	36490	38239	**4.79**	39704	8.81	39187	7.39	40019	9.67
E	2110	1775	-15.88	1825	**-13.51**	1805	-14.45	1818	-13.84

Figure 26: Comparison of the accuracy of multiple deep learning algorithms versus physical packhouse counts [Source: Kerry Walsh, CQU]

For comparison, a manual yield estimation technique of counting every fruit on a set number of trees and averaging across the total number of trees has an accuracy of approximately 40% in the CQU studies [Walsh, KA. et al. 2018].

Central Queensland University Machine Vision imaging rig, operated at 6klm/hr

Central Queensland University - Fruit detection of Mango

Figure 27: CQU Machine vision rig and fruit detection [Source: Kerry Walsh, CQU]

While fruit detection leads to accurate yield forecasting, helping to alleviate supply demand gluts, it also allows greater levels of planning leading into harvest. However, it does not address the common issue of harvesting immature fruit, caused by the inability to accurately determine the age of each fruit and what climatic conditions it has developed through, particularly when harvested by seasonal workers.

This is where the CQU and Felix Instruments combined approach of collating machine vision imagery, micro weather data from daisy chained wireless environment sensors placed throughout the orchard and data collected via Felix Instruments Near Infra-Red (NIR) Dry Matter fruit maturity guns becomes the most practical application of this technology. The result is “FruitMaps”, a 'heat map' identifying and recording flower initiation via machine vision, correlating this with temperature data, and finally NIR Dry Matter results, to determine where the most mature fruit is in the orchard and where and when, harvesting should begin.

Traditionally a harvest would begin at the start of a row and finish at the end. Looking at the fruit maps there is an area in the middle of the rows that has been late to develop flowers, therefore maturity will be significantly different to the fruit at either ends of the rows.

Figure 28: CQU and Felix Instruments 'FruitMap' showing visual representation of flowering incidence and fruit maturity [Source: Kerry Walsh, CQU]

Figure 29: FruitMap one week later showing the increasing flower load [Source: Kerry Walsh, CQU]

Currently, it is not economical to pick individual trees, or even small selections of trees per row with a manual labour force, but this is where the CQU/Felix Instruments solution completes the circle. The CQU team is also developing a robotic harvester to pick fruit, based on data compiled throughout the season in FruitMaps. This data will be 'plugged into' a robotic harvester able to navigate to areas of, or even exact pieces of, fruit and harvest only what is mature.

Addressing harvesting by seasonal workers

Without out the WHV scheme, Australian orchardists could not harvest fruit. Reliance on backpackers, even with an indefinite WHV scheme, still presents some challenges. Due to the short seasonal nature of fruit harvest, workers have no interest in the longevity of their role, and therefore no interest in taking care during harvest. Not only addressing the labour supply and cost issues, robotic harvesting also promises repeatable quality of harvest handling.

During a conversation with Dan Steere, CEO and Founder of Abundant Robotics, California, it was evident Dan grew up surrounded by agriculture as he took a farmer-first approach in developing his robotic apple harvester. He consulted with growers on what they needed, rather than a 'build it and they will come approach'. Mr. Steere is expecting to sell his first machine this apple season in Washington State. When asked why he was building a robotic harvester, Dan said he could envisage an impending labour disaster [Steere, D. 2017].


Figure 30: L-R: Abundant Robotics robotic apple harvester and unique vacuum arm picker, intended to reduce harvest losses through bruising [Source: Dan Steere]

Similarly, Fresh Fruit Robotics in Israel is a partnership between the farm manager and roboticist of Avi Kaheri, one of Israel's largest orchards, and Gad Kober who had considerable success in business development and commercial law [Kober, G. 2017]. The combination of these complementary skills has resulted in a machine capable of picking 10,000 fruit/hour or approximately four fruit per second. Mr. Kober said he was building a robotic harvester because "*nobody wants to do hard work anymore and even those that do it now, are damaging* *so much fruit because they don't care*". He expects his machines to replace 25-30 pickers and says one machine will harvest 100 acres in the required timeframe.

Figure 31: L-R: Fresh Fruit Robotics Israel apple picking 'grabber' and robotic harvest showing the 'drop bag' under the picking hand [Source: Gad Kober]

Robotic harvesting opens up a new world of opportunity to address the increasing pressure on growers to be able to accurately track and trace their produce, for not only food safety, but also leverage providence marketing. The author calls this 'digitising the fruit'. It is possible, with mechanised harvesting, for every piece of fruit to be uniquely identified using DNA spray technology such as is available from a start-up in California named SafeTraces. Inc. This identification can be followed through the packing shed where the DNA Spray identifier is allocated a block on a blockchain and a unique QR code is either printed on individual fruit stickers or laser etched on to the skin for the consumer to be able to scan at point of sale. This might all sound a bit futuristic currently, and maybe a better initial use of this technology is to combat the growing problem of food fraud, either way, this is not possible without mechanized harvesting.

Chapter 5: Challenges to Technology Adoption

The author posed a number of questions to those met in this research, such as “Why are there not robots performing all these tasks on-farm today?” The consistency in answers was striking.

The challenges to adoption identified were:

- Ageing farmers and lack of technology literacy.
- Cost of entry.
- Lack of trust in the technology.
- ‘Robots are taking the jobs’ rhetoric.
- Lack of legislative/legal/insurance framework.

Below is an analysis of the implications of each of these hurdles, and an attempt to de-bunk them.

Ageing farmers

The rhetoric around the increasing average age of farmers globally has become almost conventional wisdom and while it is difficult to disagree with the raw data, there are some important considerations in the interpretation. A 2016 article published by the Australian Farm Institute, summarises this well:

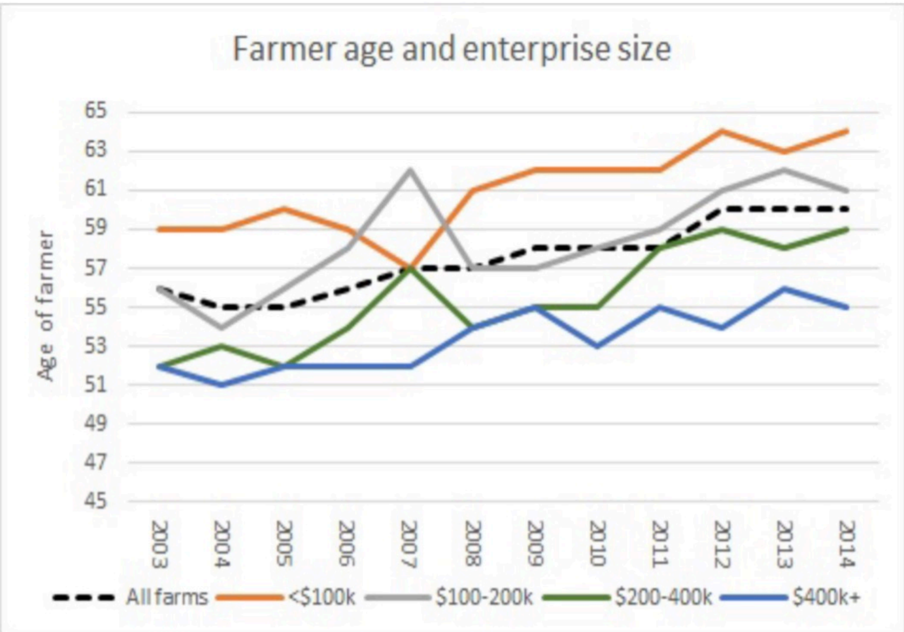


Figure 32: Farmer age and enterprise size [Source: AFI article, “Will ageing farmers limit future farm productivity, Mick Keogh, 2016]

"What the graph shows is that the average age of farm owners or managers actually decreases with farm size. The oldest group of farmers are those with farms that have an annual output valued at less than $100,000 per annum. This is consistent with the "tree-changer" narrative or could also be a result of down-scaling by older farmers who sell off most of their farm but retain a smaller block as they move into retirement. Given that 30% of total farms are in this category but that they collectively produce only about 6% of farm output, the greater age of this group is unlikely to impact on overall farm sector productivity. At the other end of the scale, there are 25% of farms which have more than $400,000 in annual output, and which collectively account for more than 75% of total agricultural output. Based on the ABARES data, the farmers and managers running these farms are an average of almost ten years younger than the average age of the farmers owning farms that are in the smallest annual output category, and five years younger than the 'average' Australian farmer." [Keogh, M. 2016]

Mick Keogh continues to unpack this in his address at the AFI Digital Farmers Conference in June 2018:

"…having either staff or service providers available with these (technological) skills will better equip any agricultural businesses to transition towards the increased application of intelligent automation that is inevitable in the future."

The trend, and need, is already apparent in Australian agriculture, and it is evident that the 'old farmers' barrier to tech adoption will, in time, become less significant.

Cost of entry

As a value proposition becomes greater, adoption increases, which scales production, in turn reducing costs.

When discussing cost, it is important to understand value. "*The price of anything is the amount of life you will exchange for it*" [Thoreau, HD. 1853]. Currently the cost of a Precision Maker retrofit of an existing tractor is approximately €50,000, with a return on investment of three years at 700 hours/year. A GreenBot has an entry level purchase price of approximately €120,000. The challenge to the GreenBot cost of entry is how specialised it is. The opportunity to offset the cost is limited in comparison to the tractor conversion because the tractor represents a far greater value, as it can perform any number of tasks. By the same argument, as the technology improves and the combination of multiple technologies/outputs such as the addition of machine vision scanning and the autonomous spraying, for example, the GreenBot begins to represent a wider and greater value. Much like a typical smartphone is the combination of many individual technologies.

Twenty years ago, the technology used today that is combined into a typical smart phone, could have individually cost $3.6 million [ZDNet, 2014].

In time a parity will be reached between two converging lines of demand and supply. The cost and availability of labour, increases in the administration of labour, food safety regulatory pressure, reduced farm profits and pressure to grow more from less (demand), will meet the decreasing cost and increasing value of this technology (supply). History has proven this time and time again with the 'adoption curve'.

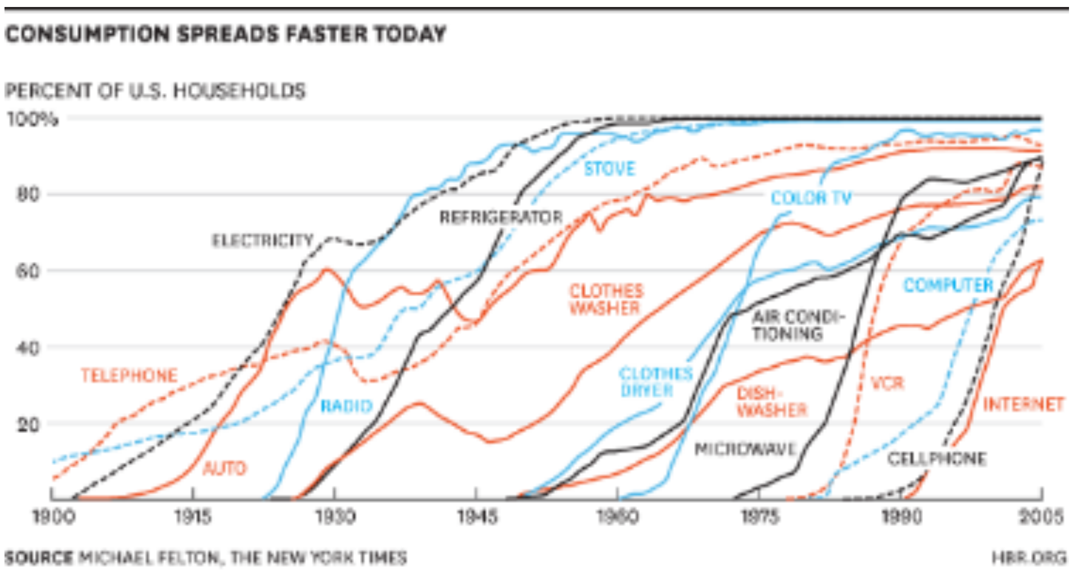


Figure 33: Traditional "S" adoption curve becoming an "I" curve due to technological advancements in global communication [Source: Michael Felton, New York Times, 2017]

Lack of trust in technology

The traditional adoption curve is becoming sharper in recent years, comparing the adoption of the clothes washer versus the cellphone. This can be explained by understanding the "Diffusion of Innovation" theory, popularised by Everett Rogers, a Communications Professor who coined the term "early adopter" [Rogers, E. 1995]. A key component of the Diffusion of Innovation theory is that for an idea to flourish, it requires a strong social network to facilitate spread and reaffirmation. Rogers wrote the first version of his book in 1962, long before the introduction of modern social media networks. Today, good ideas spread faster due to vastly wider and internet connected social networks.

Rogers argues that trust is earned from reliability, usability, consistency and offering a value proposition that is worth the risk of investment (time and money).

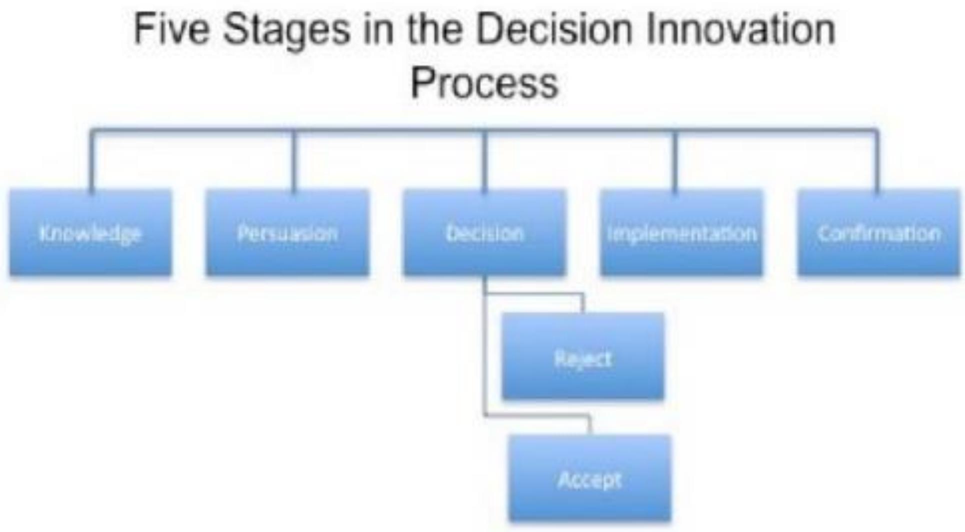


Figure 34: Five stages in the decision innovation process [Source: Diffusion of Innovations, 1962, Everett Rogers]

First, knowledge is gained of a new innovation. Then persuasion is required. Then a decision is taken to adopt or reject, and if adoption is accepted, it is followed by implementation. Finally, if there is a positive validation of the technology, the experience is shared with others. An AC Nielsen 2015 study showed that 83% of respondents across 60 countries would make a purchase based on recommendations from people they trust [AC Nielsen, 2015].

The damaging 'robots taking jobs' rhetoric

Much like the ageing farmer discussion, this popular rhetoric is impeding advancements in this field. Job redundancy is a very powerful political issue, and governments are measured by their unemployment figures. Job growth figures are substantial factors in economic policy decisions, so as much as the 'Robot Apocalypse' media coverage may seem benign, it is exceedingly damaging to the progression and adoption of technology, and the creation of new industries, economies and jobs.

There is no argument that automation will result in job loses, but just as the invention of the motor car resulted in fewer farriers, it created a global industry projected to ship 81.5million cars in 2018 and employ over 50 million people worldwide [OICA, 2018]. Combining agriculture and technology is creating an entirely new industry: AgTech. This will require employment in research and development, manufacturing, distribution, sales, service and support, and by default, AgTech will have a considerable footprint in rural agricultural production regions.

Rural Australia needs a new industry to combat rural unemployment and rural "brain drain". For too long bright, capable kids from rural communities have had little option but to move to the cities to reach their earning potential. Millions are spent every year by government attempting to entice industries to set up in rural Australia, with little success. The move of Canberra-based Australian Pesticides and Veterinarian Medicines Authority (APVMA) to Armadale in 2017 is an example of this regionalisation strategy, and yet 12 months on, almost half of the original staff resigned, despite an increase in the relocation assistance package offer from AUD$30,000 to AUD$55,000 and increases in the already attractive retention bonuses [ABC, 2018].

Agriculture is the stalwart of rural economies. For decades, investment in agriculture has been the 'low margin, low risk', long-term choice. Investment in Rural Agricultural and Autonomous Technologies (RAAT) through the support of entrepreneurs and on-farm adoption will 'plant the seed'. Manufacturing, distribution, sales, service and support of RAAT creates employment, rallying rural economies. Career paths will form in ways currently not even known, providing attractive rural opportunities for young people.

In 2014, the Singaporean Government announced support for SME businesses adopting cutting edge technology such as robotics, and data analytics, providing 80% of the implementation costs up to SGD$1million. In a 2016 budget speech, the Wee Meng Construction Company case study was used to outline how investment in robotics, through the 2014 announced scheme, allowed Wee Meng Construction to address their labour void. Below is an excerpt from the speech:

"…This is Wee Meng Construction, a local steel fabrication SME serving the construction industry. Like other SMEs, they could not attract young and skilled Singaporeans. So, they did three things: First, they adopted a new robotic cutting system, which increased productivity of the cutting process by 18 times. Second, they mapped their productivity gaps to identify improvements. And third, they trained their staff to operate the new machines, increased the pay of trained staff by 10-20%, and built an in- house robotics team. So now, new Singaporean employees joined the firm, and they reduced their hiring of foreign workers …"

Governments also need to re-think agricultural education in schools. The ubiquity of the internet will negate the need for recalled knowledge of most, if not all of what is being taught in agricultural science classes in secondary schools today. The agricultural students of tomorrow will require a broad combination of skills more in line with the students in today's computer sciences, electronics and mechanical engineering classes. Instead of spending millions in moving industries and enticing non-rural professionals to rural Australia, RAAT has the potential to be an entirely new rural industry, requiring employment of young people who already live, and love, rural Australia.

As this rhetoric is such a common and polarising topic, the question was asked of all interviewees, "*How do you respond to people who say robots will take all the jobs*?"

Overall the response was in unison, "*We are only creating solutions to an already existing labour supply void*" [Gad Kober, FFRobotics, Israel].

One interesting response from Mr. Hannes Hannenheim of Raussendorf Munich, developer of the Cesar autonomous orchard robot, he saw his core role as an engineer to develop solutions that make working environments for humans safer. Almost all interviewees also stated that what they are developing is basic human progress.

Machines are better than humans at performing highly repetitive, time consuming, precise tasks that require no cognitive input or decision making. Cognitive humans need to be freed-up to complete complex decision-making tasks and leave the robots to the dangerous, monotonous and mundane.

Legislative/legal/insurance framework

The lack of legislative framework to allow the use of autonomous vehicles on farms is often touted as a major barrier to adoption. It stops the creation of a legal liability framework, which in turn stops the creation of insurance guidelines which slows the adoption of the technology.

While this may be true at the mass adoption stage, the AgTech industry is in the innovator and early adopter phase, and as Andrew Bate, CEO and Founder of Swarm Farm Robotics states perfectly:

"… we should not seek to regulate an industry before it exists. History shows that innovation happens as an industry evolves, then legislation follows. Seatbelts, Airbags and ABS brakes were not legislated into existence. The innovative car manufacturers released them on their

luxury model cars for competitive advantage, and they proved to save lives. After that stage, legislators made them compulsory fitment to all cars to save lives. We must not let bureaucrats stifle innovation before an industry exists."

Mr. Bate also made another interesting point:

"We have had autonomous vehicles such as lateral shift and travelling irrigators operating autonomously for decades now."

In discussion with Tim Leach, Elders National Product Manager of Technical Insurance, he stated:

"We don't know yet if automation will reduce claims (machines don't become bored and distracted but they are not always intuitive unless programmed to be so); or will claims increase (mechanical or software failures). Then there is the hybrid of automation with an operator who can intervene.

"Also, the legal environment is uncertain. A harvester operator (person) is usually responsible if they fail in their duty of care to prevent escape of fire. A machine cannot be responsible – are the fail safes in place reasonable thus removing liability? If so a neighbours' property insurance should increase because the ability of insurers recovering from the harvester operator is reduced…."

When discussing existing coverage, Mr. Leach advised:

"…our standard policies do not exclude liability from or damage to automated vehicles. The owners and operators are covered and at this point in time, we have no data to charge more nor less premium."

Conclusion

Significant investment has been made through universities and research institutions all over the world to reduce horticultural dependence on manual labour, with almost no commercialisation.

The most significant deployment of robotic/automation technology has occurred through development partnerships between growers and private companies.

Australia can benefit from hindsight, recognising the trends affecting horticultural production in the EU particularly over the past decade, such as increasing regulatory burden, bans on common pesticides, increasing unpopularity of migrant labour and rising land values.

Already proven technology has had limited adoption in Australian orchards.

Horticulturalists need to consider what their businesses will look like tomorrow without a migratory labour program, increasing scrutiny on best practice and a requirement for complete paddock top late traceability.

Every new planting today needs to be 'robot ready' and adopt already proven techniques such as high-density systems, automated irrigation and fertiliser control systems using precision moisture probes to take the 'emotion' or guess work out of water and nutrient applications. These robust, mature systems address input challenges, and are a user-friendly introduction to technology to measure, react and record farm activities helping to build trust and technological 'literacy'. As seen in Israel, this technology is so widely adopted, it has become ubiquitous. Also, avocado planting densities of up to 1,110 trees/Ha have proven to be yielding almost six times that of the Australian average in Israel. The infrastructure and management of high-density orchards prepares the orchard for machine vision, requiring smaller, almost 2D trees, while also addressing the greatest challenge for robotic harvesters, reducing the internal volume of the canopy.

These low impact changes can be implemented with a change in mindshift today, and are not only sound agronomic based decisions, but will also demonstrate leadership and a genuine need for future technology to industry and government.

Peak industry bodies need to support on-farm adoption. Pre-competitive stage evaluations of commercially available autonomous irrigation/fertigation systems along with farm management platforms, with a solid extension/communication plan from the beginning will help facilitate the 'diffusion of innovation' of these highly beneficial systems to build trust in technology on-farm and kick-start technology education. Initiate a greater focus on high density planting management with rootstock, pruning and growth control chemical projects, yield maximisation with a goal towards 2D tree architecture. The current "Small Tree High Productivity Project" part of Hort Innovation's project AI13004, is an excellent example, but there has been no financial record of additional labour requirements for high density management, which is the first question every grower asks at open field days. Levy funded projects should require grower partners before they are approved, as too many take a purely scientific approach, with little regard for the practical implementation.

The Israeli Plant Grower Board model requires all projects to have on-farm grower partners so that the application of research can be tested in a real-world setting. If a project cannot get grower support by majority vote or an on-farm applied partner, it is deemed not relevant and does not receive approval [Gafni, U. 2018].

Another example of an industry addressing low commercialisation of research is Wageningen University and Research. WUR has recently altered its grant funding model due to feedback that 'nothing ever got commercialised'. Now all projects need an applied partner as well as a commercialisation partner before the grant is approved [Kempenaar, C. 2018].

In the 2013 Organisation for Economic Co-operation and Development (OECD) ranking of country research and industry collaboration, Australia came last [OECD, 2013]. Until there is a more whole-of-industry collaborative approach to project approval and funding, the same results will occur.

Government has an opportunity to shift funding toward the support of Robotic and Agricultural Automation Technologies (RAAT), given that it has the potential to be an entirely new industry, and by default, a rural industry.

Since the 1990's, the Federal Government has chipped in $300 million dollars/year to Telstra to deliver and maintain landlines across Australia under the Universal Service Obligations [Coutts, R. 2015], something that would have been uneconomical to complete without Government support.

Governments must recognise there are innovation leaders in the agricultural field who, as shown in the Singapore example, with the support of government to assist with implementation costs, will provide the social network leadership required to reaffirm the technology, build trust and initiate adoption.

Horticultural producers are facing real, current and valid future challenges to existing production systems, maturing technologies from external industries are now at a stage they can make a substantial impact if implemented into horticulture. It will take brave innovators across all sectors of production, industry and government to lead change and assist in the adoption of these changes sooner rather than later.

"Tell me and I forget. Teach me and I remember. Involve me and I learn" Benjamin Franklin.

Recommendations

This report has aimed to be a practical distillation of the research to be considered relevant to Australian orchardists today. It is not intended to be a policy recommendation reference, but it would be remiss not to offer recommendations that could expedite the adoption of the technology discussed.

On Farm Recommendations:

- Consider every new planting today to be "robot ready". Use GPS plotting for tree spacings and block creation. A handheld GPS can be purchased today for less than AUD $200.
- Challenge traditional planting densities with higher density systems. Smaller trees require less water and nutrient, freeing up resources for fruit production rather than timber and leaf.
- Begin a technology literacy education journey by adopting existing, proven technology such as autonomous irrigation, fertigation systems and farm management software.
- Consider the technological knowledge required into the future and employ accordingly.
- Picture the business without a temporary worker program.

Industry Recommendations:

- Focus on technology adoption. Workable technology exists in the drawers of universities all over the world.
- Only approve new applied technology projects that show collaboration between farmer, researcher and commercial developer, with a strong extension and communication plan to ensure practicality, commercial viability and widespread adoption.
- Initiate a technology literacy education program using existing, proven technology such as autonomous irrigation, fertigation systems and farm management software.

Government Recommendations:

- Commit to Robotic and Agricultural Automation Technologies (RAAT). This has the potential to be an entirely new industry, and by default, a rural industry.
- Provide attractive benefits to RAAT entrepreneurs to kick start the industry from the ground up.
- Recognise that new industries require regulatory leniency.
- Facilitate investment in RAAT start-ups with attractive frameworks for both domestic and international venture capital inflows.

- Provide 150% tax deductions on robust, proven new technologies to support innovative farmers absorbing the initial financial burden of future proofing their farm by adopting new technology.
- Increase support for new technology industry projects with strong, viable commercial outcomes derived from whole of industry collaboration.

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Plain English Compendium Summary

Project Title:	**Robotics, Automation and Emerging Technology for the Future of Horticulture**
Nuffield Australia Project No.:	1719
Scholar:	Matthew Fealy
Organisation:	HortRobotics Australia 289 Springs Rd Mareeba, QLD, 4880
Phone:	+61 (0) 402 412 471
Email:	matt@hortrobotics.com
Objectives	Primarily to take a 'farmer first' approach to investigating what early adopter technology currently exists, or is soon to exist, to addresses current trends threatening orchard production systems. Furthermore, to investigate why these technologies are not widely adopted and attempt to make recommendations to facilitate the on-farm implementation of these emerging technologies.
Background	I manage a commercial mango, avocado and lime orchard and became increasingly frustrated with the regular over promising and under delivering of AgTech. I recognised major future challenges to our current production systems including the heavy reliance on backpacker labour, increasing financial pressure with on farm margins falling while input costs were rising and consumer trends demanding farmers to 'grow more from less'.
Research	Travelled to 13 countries over two years interviewing technologists, venture capitalists, research institutions, founders of the world's leading ag robotics companies, policy makers, insurance institutions and most importantly, orchardists who have adopted some of the world's most innovative, bleeding edge technology.
Outcomes	The study revealed that there are some robust technologies available today that adequately address major commercial challenges but are not widely adopted due to often only perceived challenges. There are also some promising technologies available in the not too distant future that will have significant impacts on our production systems, requiring growers to consider changes to their farms today to be able to take advantage of them tomorrow.
Implications	Brave pioneers in the three pillars of farm, industry and government are going to have to collaborate with a long-term view to realise the benefits of these technologies.
Publications	Presentation at the 2018 Nuffield National Conference, Melbourne