Chapter 26

From conservation to automation in the search for sustainability

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Introduction

Barr and Cary (1992), in their book "Greening a Brown Land", describe Australian agriculture as a "*…200-year search for sustainable land use*". The problem with that notion, as they point out, is that sustainability is not fixed but evolves with time as community attitudes change – the goal posts are forever moving. This means that there is a constant need to innovate in order to meet emerging challenges and grasp opportunities – and this need never abates. However, unlike the Green Revolution of the 1960s and 1970s, when the focus was to bring know-how together for mass food production, the current paradigm has food production as the aim, but with a range of caveats such as minimising greenhouse gas emissions, protecting the environment, improving human health and meeting market demands such as low pesticide residues, acceptable breeding methods and traceability. At the same time there needs to be efficient, profitable and resilient farm businesses to provide continuity to the market and to ensure quality of life for farm families and employees. Sustainability thus has several components including financial (including productivity), environmental and social.

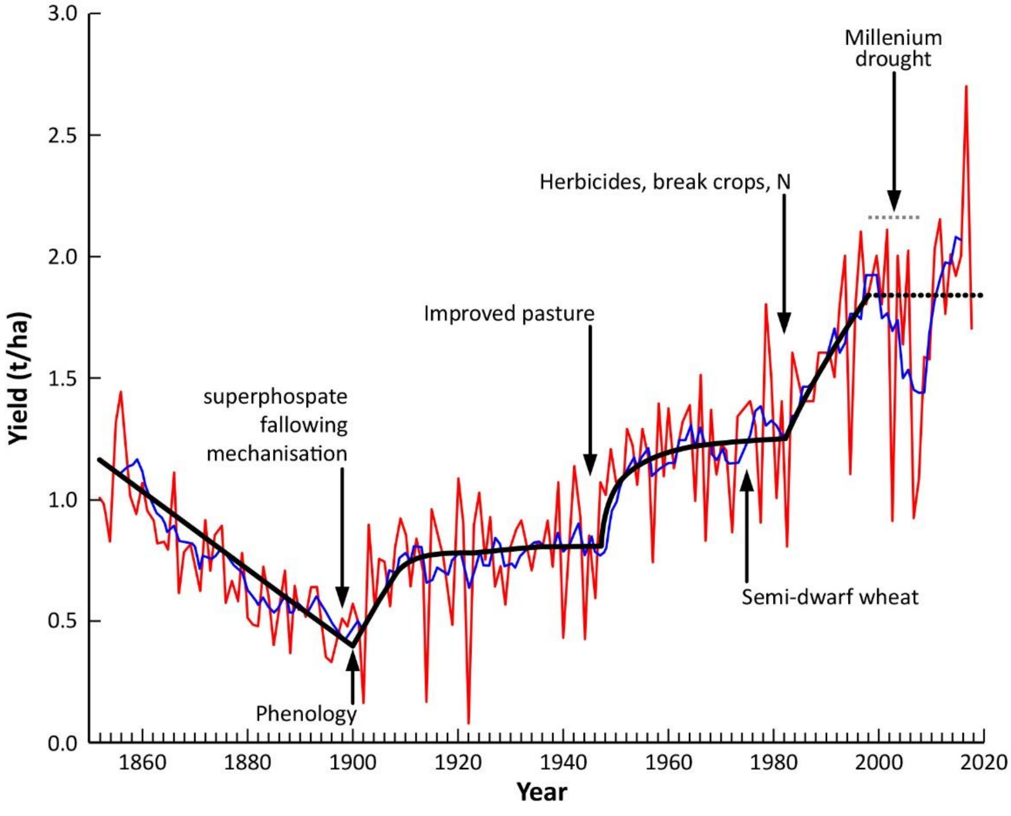

Figure 1. Growth in Australian wheat yields and technologies driving changes (updated from previous versions by Donald 1965, Angus 2001, Kirkegaard and Hunt 2010). Annual yield (red), 5-year running mean (blue), decadal trend (black)

This notion in respect of *productivity* is expressed in the oft-quoted, and here updated, Figure 1 describing the long-term trend in national wheat yields in Australia showing the key innovations and subsequent impact on productivity. The substantial increase from the 1990s largely represents the period of innovation reported in this monograph and should be cause for some sense of achievement for Australian growers and agronomists. But the experience of the last 15-year period, where yields have seemingly plateaued against significant climate-induced volatility (Hochman *et al*. 2017), emphasises the need for ongoing innovation to close the existing exploitable yield gaps. There is optimism among agronomists and other agricultural scientists working with wheat that technological innovation will continue to close the gap. Such optimism is cautiously warranted (*e.g*. Fischer *et al*. 2014, Robertson *et al*. 2016) given the unprecendented challenges that have been addressed along the wheat yield trajectory in Figure 1 in the past (*i.e*. fertility decline, erosion, droughts, salinity). Notable in the broader diversification of agriculture beyond wheat has been the major developments and progress in other crops such as canola and cotton production over the past 30 years, underpinned by effective research and development. This monograph catalogues the substantial research effort in agronomy that has been undertaken over the past 30 years and emerging innovations, presented as a snapshot in Box 1.

Box 1 A snapshot of some of the current and future innovations and trends highlighted in this monograph

Technologies to deliver benefits through:

- virtual fencing, GPS collars for livestock to enable precise, spatial grazing management
- automation to enable operator to control smaller, multiple units reducing operation time and maximum flexibility
- communication between implements, tractor, human operator
- sensors identifying soil moisture with seeding depth adjustment, crop nitrogen status, precision fertiliser placement matched to crop demand, weed presence for precision removal

Farming increasingly data driven with gains made by:

- improved weather forecasting, remote sensing imagery, automated routine operations, digital management of compliance

Improved IPM outcomes through:

- non-chemical technologies, competitive crops and new herbicides for weed control
- ‘smart’ trapping, predictive modelling, in-field molecular diagnostics, improved varieties for insect control
- pre-plant testing, tolerant varieties, improved fungicide efficacy, perhaps microwave radiation for disease control

Agronomy increasingly privatised through;

- agronomic advice
- technical services such as IT, data analysis, technologies, decision support (DSS)
- greater emphasis on innovation rather than research *per se*

Management capability critical;

- to build flexibility and resilience into the farm business
- to address climate change uncertainties including minimising emissions
- to identify best combinations of GxExM
- to benefit from increasing digital agriculture; digital systems will enable producers to respond better to pressures of compliance, provenance and best management practice

In some cases, productivity improvement has been the result of refinement in the application of innovations occurring in much earlier decades. However, the sense of achievement, as Barr and Cary (1992) indicate, needs to be moderated as new challenges, both agronomic and non-agronomic, impact on the capability of crop producers to manage sustainable farm businesses. We have learnt that, as one challenge is met, others emerge and that is evident in the contributions in this publication.

Significant advances have been achieved in that time in our knowledge of the systems needed to be productive and environmentally sensitive in the Australian landscape. There has been a concurrent revolution in machinery capability and technology that will provide opportunities for substantial benefits if employed appropriately. Such advances are largely within the control of the producer. But there are many influences, not in the scope of management, which add to the risk of agronomic practice and which should not be overlooked as sometimes they can assume substantial influence. We complete this monograph by reflecting on the some of the risks as we perceive them in the search for a sustainable agronomic future.

Risk and sustainability

Sustainable productivity and profitability

A moment of reflection on the productivity big picture is timely. Keogh (2012) considered the trend estimates of various sectors and industries in the Australian economy for the period 1975 to 2011 in terms of the variability in output (which he calls volatility). The data show agriculture to be the most volatile sector and around 2½ times that of the average of all sectors. Figure 1 suggests that in the years since then, volatility has increased, at least for our major crop wheat.

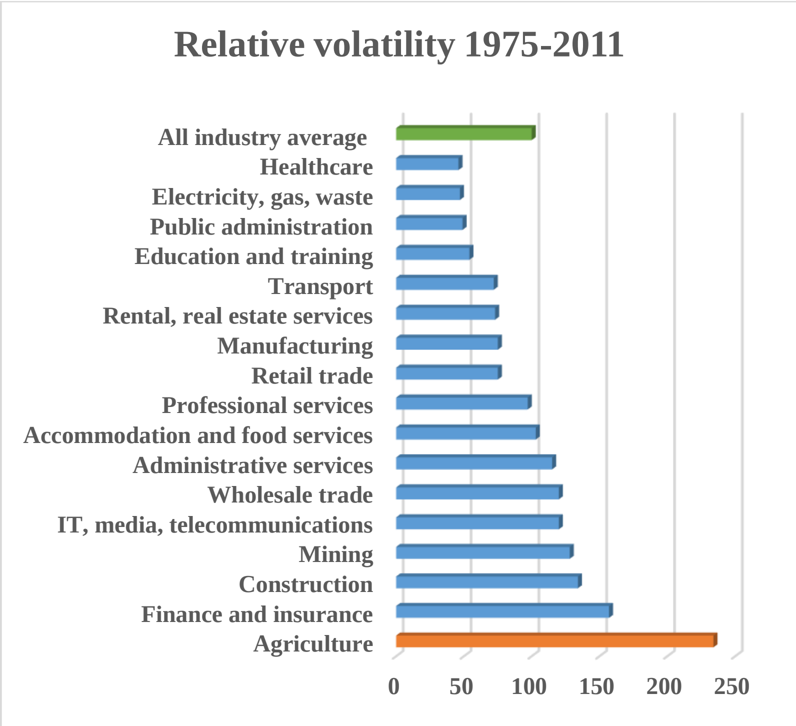

Figure 2. The relative volatility of annual Australian output for 17 sectors of the Australian economy from 1975 to 2011. A trend estimate of volatility was determined by a third order polynomial trend line, using least squares. The standard deviation of the percentage variation between trend and actual output was calculated and then indexed around the average, with average for all components set at an index value of 100 (Keogh 2012)

A closer analysis of agriculture's performance is shown in Figure 3 which demonstrates that volatility itself has varied significantly. It unsurprisingly points to rainfall incidence as a likely major influencer of variability – the period 1985-94 was a relatively wet period and coincided with the focus on water use efficiency as a measure of agronomic performance (French and Schulz 1984a, b, Cornish and Murray 1989). The other periods have had serious drought years and so production was compromised substantially on large parts of the cropping zone. The trend to more specialised cropping-only farms is also likely to have caused an increase in the volatility. What is clear from these data is that, overall, agronomy R&D and improved production on-farm have not made a discernible impact on the risk involved in growing grains, oilseeds and fibres. Climate change imposes another layer of complexity on the already complex operations of agronomy.

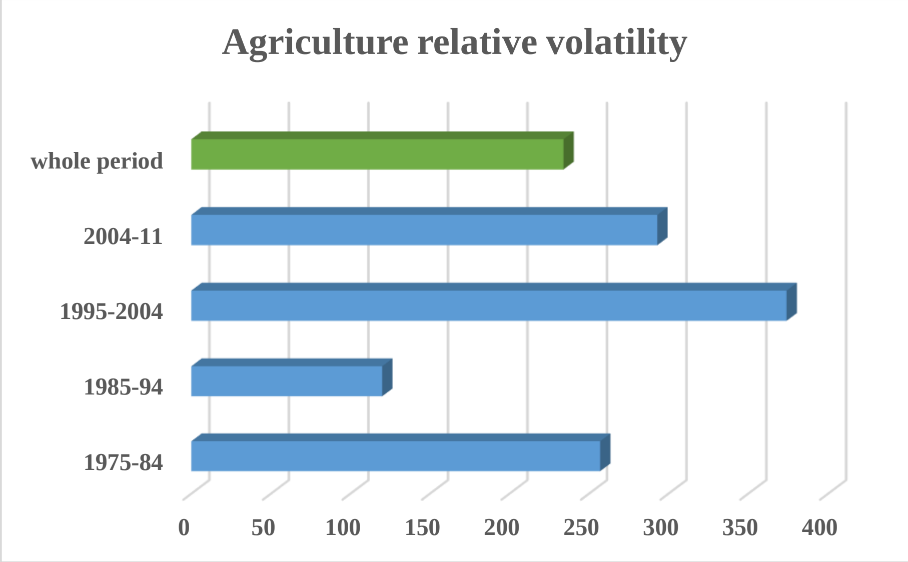

Figure 3. The relative volatility of annual Australian output of agriculture over the period 1975-2004, considered in 4 component periods. Overall average for all sectors is 100.

Another measure for context is the estimate of volatility for Australian crop farmers compared with those from other producing nations (Figure 4). Among 15 countries over a 38-year period, the Australian index for crop production was shown to be much higher than that for any other nation, was 24% greater than the next highest country, and more than double the average of all other countries considered.

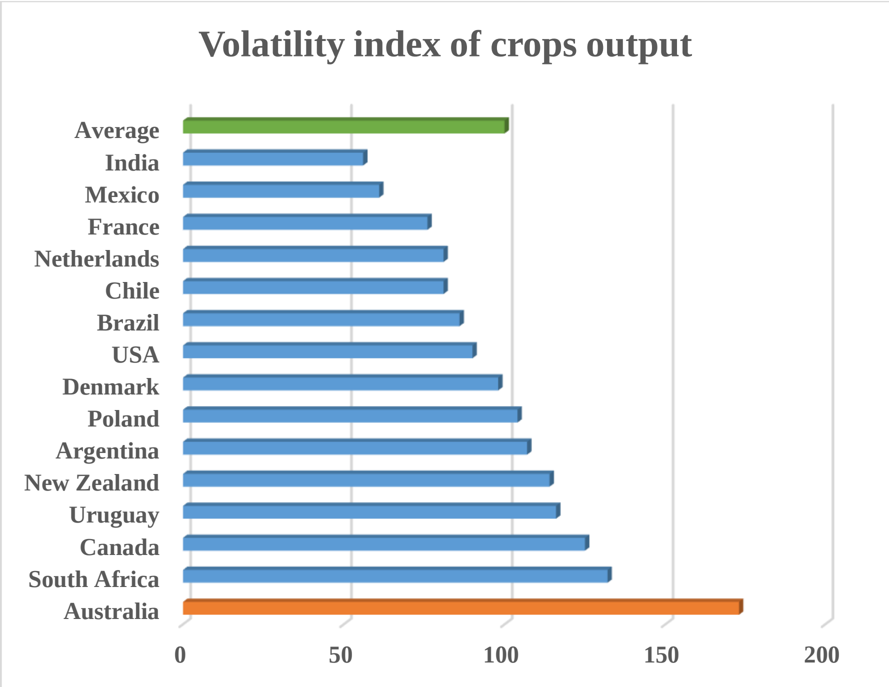

Figure 4. The volatility index of crops output for 15 nations across the period 1961 to 2009. Average volatility is 100 for the nations combined). Volatility estimates are determined as described in Figure 2 (Keogh 2012)

These data explain, as described by Keogh (2012), that Australian farmers, and particularly crop producers, operate in a more volatile business environment than farmers of other nations and other sectors in Australia. While the variability in output, in some cases, could be due to wise decisions not to plant in some seasons, other data suggest this is not a significant factor. Risk management would seem to be a major priority for farm businesses and, accordingly, for the R&D that supports those businesses. There are many examples in the preceding chapters of research that addresses aspects of risk but clearly there is still much to do, especially given the climate predictions for more variability and extreme events. The moves towards sensor technology for improved spatial and temporal monitoring of soils, plants and weather, advances in plant biotechnology to deliver crops with resilient characters, and more reliable seasonal forecasts for better planning will help, as will better spatial data capability and insights from big data analytics.

Environmental sustainability

Much has also been achieved in the last 30 years in environmental management. As a continent which has the oldest soils and is the driest of the inhabited continents, Australia has had a shared but regrettable history (*i.e*. the first 150 years post-settlement) of soil erosion and soil degradation. The combination of poor soils, bare fallowing and excessive cultivation resulted in the dust bowls of the 1930s and again in the 1970s and early 1980s. Environmentalists rightly complained that agriculture was silting up waterways and was responsible for their eutrophication. The evolution of CA in its various forms has been a response to those challenges and has succeeded in reducing the incidence and severity of erosion events and, thereby, the siltation and eutrophication of the waterways. In the process much has been learnt about managing irrigation and dryland salinity, soil acidity and other environmental challenges.

The adoption of NT farming systems has enabled greater economic resilience in farm businesses. However, NT, as currently practised, is highly dependent on the input of synthetic chemicals which itself has brought new challenges both in agronomic and non-agronomic domains.

Social acceptability and political reality

Although agriculture has been an essential component of Australia's identity and provided quality food and fibre along with quality of life, the sector has been the target from time to time of activists undermining the confidence of communities that food is safe, the environment is well managed and animal welfare is protected (Lockie 2015). In some cases, this has compromised the financial prosperity of farm businesses and threatened the livelihoods of farm families and their communities. In some situations, the right to farm for individuals has been challenged, and the social licence for industries has been brought into question. In extreme cases recently, activists have entered properties and businesses, resulting in families feeling threatened and biosecurity of operations being placed at risk. There has been government response in legislation outlawing such action and imposing high penalties, although the impact of these responses is unclear and the movement remains active. Emerging trends in the perceptions and beliefs about food by the urban majority, often largely disconnected from an informed scientific debate about its production and safety, are unlikely to diminish. Defending sustainable practices and engaging more with customers in 'paddock to plate' or 'farm to fork' engagements will be crucial.

At another level there have been campaigns with the potential to derail critical aspects of conservation agriculture. Two are particularly relevant to agronomy, *viz.* the ongoing anti-GM movement and the more recent anti-glyphosate saga. Although there is a lack of scientific evidence to support either campaign, the use of social media, picked up by mainstream media, has created enough fear and distrust in the community that governments have responded in some cases by restricting the practice or use of these products. Some Australian States imposed moratoria for a time against the growing of GM crops and some international markets do not accept GM products. Likewise, some Australian local councils have stopped employees from using glyphosate, some countries have banned its use and others do not accept produce where glyphosate has been used in its production. Both campaigns, if successful, will have a devastating impact on the practice of CA. In some cases, 'alternative' modes of production arise and take advantage of the uncertainty that has been created by such fear campaigns. The market then determines their viability. There may be opportunities to bring elements of some alternative options into mainstream production systems and diffuse the conflict by improving consumer acceptance.

Geopolitical risk is everpresent. Locally, Lockie (2017) comments that the polarised politics of climate change for example has not served Australian agriculture well in preparing for more uncertain environments. This tends to result in reactive policies of increased drought assistance rather than the development of policy instruments that improve the adoption of risk management strategies by farm businesses. Internationally, political instabilities compromise free trade agreements and often result in re-imposition of tariffs or other trade restrictions. In reality such instability can result in either a threat or an opportunity depending on the issue and the countries involved.

Government interventions alter the risk profile for farmers. Such contributions can be imposing price floors, providing subsidies for crop insurance, direct payments and marketing loans (*e.g*. as in the USA, Maaz *et al.* 2018) and for ecosystem services. Australia and New Zealand receive the lowest level of government intervention and so farms must address their risks strategically rather than depend on governments to do it for them. Chapter 3 canvassed some of the business responses such as increasing farm sizes for economies of scale and the move to a more corporate style of management even for farm families.

Impact of technology on sustainability

It is worth reflecting that when CA commenced its rapid expansion in the late 1980s, there were no mobile phones or laptops. Computers were generally mainframe and PCs were in their infancy. Faxes had become the technology of hard copy communication. Sensor technology was rudimentary at best and the internet did not arrive until around 1993. The CA research agenda described here-in was undertaken alongside the growth and maturity of these technologies which are now taken for granted. In 2020, computer technology has capability not imagined in the 1980s and is embedded in machinery, robots and other aspects of production as an integral part of operations. We have arrived at a point where sensor technology provides the capability, but the applications are not realised as yet. Mobile phones have sophistication now (*i.e*. the 'smartphone' since 2007) that provides much capability, particularly with photography, messaging and 'apps' opportunities. The current challenge remains how best to use the capability to improve farm business decisions and performance.

The report, "Australia's Agricultural Future" (Daly *et al*. 2015), highlighted that "…*integrating deep agricultural knowledge with cutting-edge technologies (including sensor networks, robotics, autonomous systems, innovative mathematical and statistical models for big data sets and ICT) will be central to the next agricultural revolution. Agri-intelligence research is a springboard for agriculture into the second machine age, in which computer systems augment human perception and decision making in complex situations*." Much of this however depends on high band-width internet access for farmers in rural Australia – this represents a shortfall in capability as much of the production areas have little to no access to high speed internet. Success in agriculture will depend on ready access to market and weather information, to supply chains and to the service sector. Agriculture will continue to be the generator of 'big data' but its ability to prosper from such rich data will be determined by its connectivity capability, which is a current limitation. Modern farm machinery includes precision technologies that collect data on the machine or crop. Data collection and transfer capability is required to utilise that data both for machinery performance and for farm decisions: large areas of rural Australia lack mobile coverage and/or have very low access speeds (Keogh and Henry 2016).

Connectivity is the single most important enabler for digital innovation in agriculture. Where connectivity is not provided (*e.g*. by the National Broadband Network, NBN), some farms address their own connectivity needs – through LPWAN (low powered wide area network) for small packets of data, to Satellite Iot in remote locations, to on-farm WiFI networks for more complex data sets (KPMG 2019). Transformative technologies that replace labour needs, however, are likely to reduce employment opportunities and increase isolation in agriculture and depopulation of rural areas (Lockie 2018). Alternatively, they may create new jobs in the technological support area although some of these can be undertaken remotely.

Plant breeding technologies have also delivered immense value to Australian, and global, agriculture for some crops. Significant breakthroughs in the last 25 years, most notably 'genetically modified'

(GM) crop varieties, have transformed cotton production (from 1995) and to a lesser extent canola in Australia, largely in terms of insect and herbicide tolerances. However there has been little improvement so far in potential yield *per se* or in drought tolerance (Fischer *et al*. 2014, Dalal *et al.* 2017) though there is potential to deliver more in terms of adaptability, resilience and functional foods. The breeding technologies have reduced the time taken to produce new varieties by traditional means.

The Future of R&D – the 'Innovation' era

A study of innovation in Australia (Innovation and Science Australia 2017) commented that Australia became world record holders in 2017 for 26 years of sustained economic growth. Credit was given to agriculture and mining for this outcome through their "extraordinary innovation, risk-taking and export success". The Report indicated that innovation was needed to maintain a strong economy through better international competitiveness. To achieve that competitiveness would require:

- Scale-up of high growth industries and companies;
- Commercialising more high-value products and services;
- Fostering great talent; and
- Daring to tackle global challenges.

These represent a challenge to agricultural R&D. Interestingly no mention was made of traditional R&D in the innovation context.

Although there are fears that automation and the digital economy will result in job losses, such jobs are likely to be in routine, manual tasks. However technology is likely to create new, different jobs with emphasis on digital systems and '21st Century skills' such as entrepreneurialism, inter-personal skills and problem solving (Innovation and Science Australia 2017). The Report goes on to say "…rather than fearing that digitalisation and automation will erode jobs or opportunity, we should recognise that these changes will be positive for the economy, and are essential to fill the workforce gap left by demographic change, to lift productivity and contribute to GDP growth".

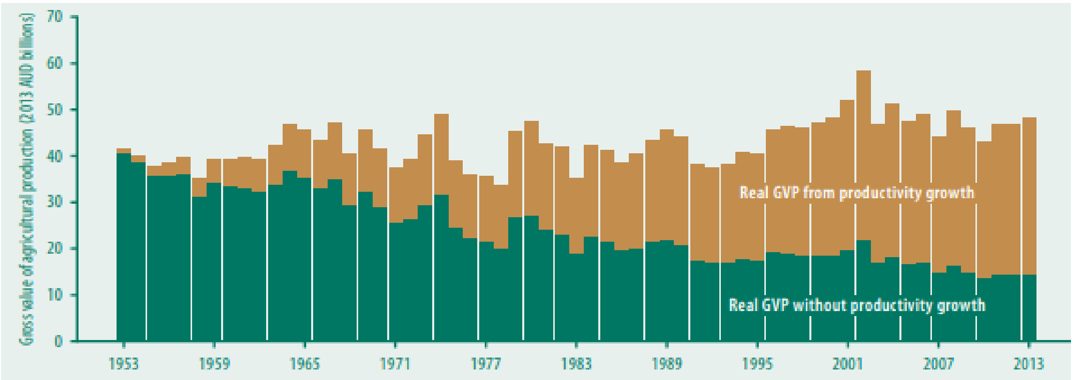

Figure 5. The value of productivity growth to Australian agriculture (From Daly *et al*. 2015)

Australia is positioned as a generator of high quality, clean and green food, and it is important that the contribution of R&D be acknowledged in that achievement. Figure 5 shows the contribution made from productivity growth to the gross value of agricultural production in Australia (Daly *et al*. 2015). While some of this progress is through application of R&D undertaken internationally, Australian researchers, including producers, can be well satisfied with their contribution. The R&D effort by Australian agricultural researchers has been undertaken in large part in isolation from the rest of the national innovation system. Lip service has been given to the National research priorities while addressing what have been the perceived priorities or opportunities for agriculture. While the major research investors, particularly the research and development corporations (RDCs) in conjunction with the Federal Government, have their investment plans, several reviews of the agricultural R&D system (*e.g*. Howard Partners 2018, Ernst & Young 2019) have noted that there is no over-arching shared vision of what agricultural R&D is or should be. There is a strong case for agricultural R&D to be more closely aligned with the national innovation system as it is likely that transformational developments will come from other sectors such as medicine, engineering or computing. Further, no country will be able to afford all the research needed in agriculture (or other disciplines for that matter) so increasing global collaboration will be paramount.

Our capacity to meet the challenges

Agronomy research performance How then does this fit with Australian agronomy research? A difficulty in evaluation is having reliable metrics for determination. The Australian Council of Deans of Agriculture (ACDA) commissioned a study of peformance based on research publications over a 20 year period from 1996 to 2015. Its veracity is subject to researchers actually publishing in recognised journals and adequately describing their research in agronomic terms. It also suffers from the lackadaisical attitude of research funders towards scientific publications. Nevertheless the numbers are insightful enough to ascertain trends relative to global performance of other players operating with similar caveats.

Figure 6 shows the annual publication numbers for papers in agronomy by Australian authors. Over the 20-year period, those numbers increased from 408 in 1996 to 683 in 2015, an improvement of 67%. However, if the share of global publications is considered then there has been a decline in share of 30% over the same period. Other countries have increased their publications more than Australia has.

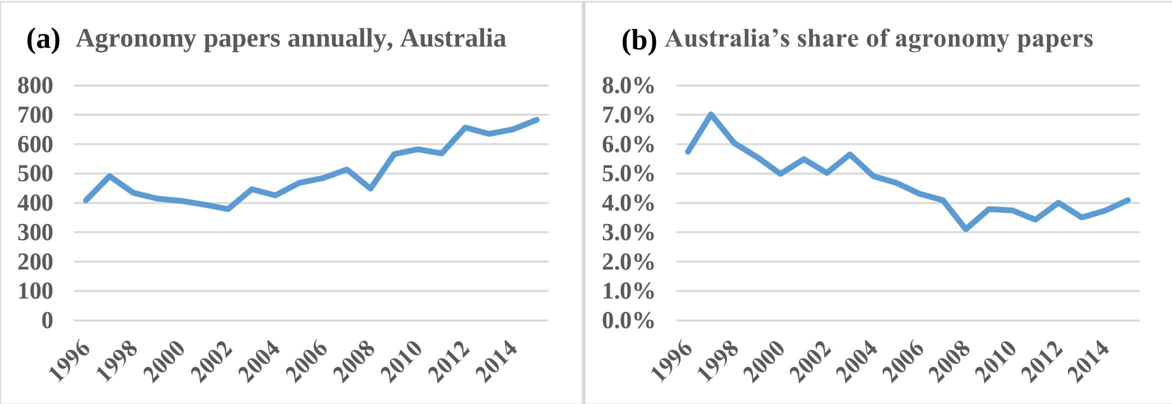

Figure 6. (a) Number of papers in agronomy published annually by Australian authors and **(b)** Australia's global share of agronomy papers annually for the period 1996-2015 (ACDA unpublished)

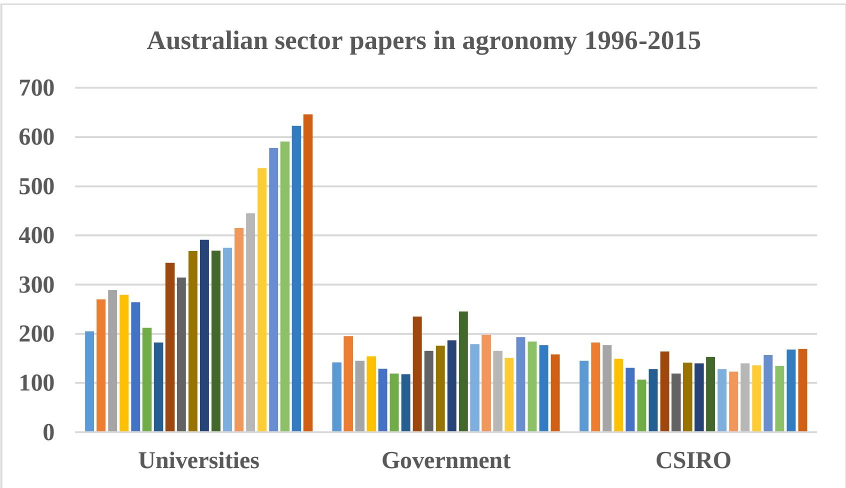

Figure 7. The source of agronomy papers from Australian research organisations annually for the period 1996-2015 (ACDA unpublished)

There is also a long-term trend regarding who provides the research publications in Australia (Figure 7). Over the 20-year period, CSIRO and government agencies have been relatively stable in publication numbers produced but universities have had a 215% increase over that 20-year period. Universities have had publication numbers as a metric for individual promotion and for institutional research grant quantum and so the trend is not surprising, although the extent may be since universities are represented in over 70% of the publications. Government numbers are also misleading as there are big discrepancies between the number trends of different state agencies (data not presented).

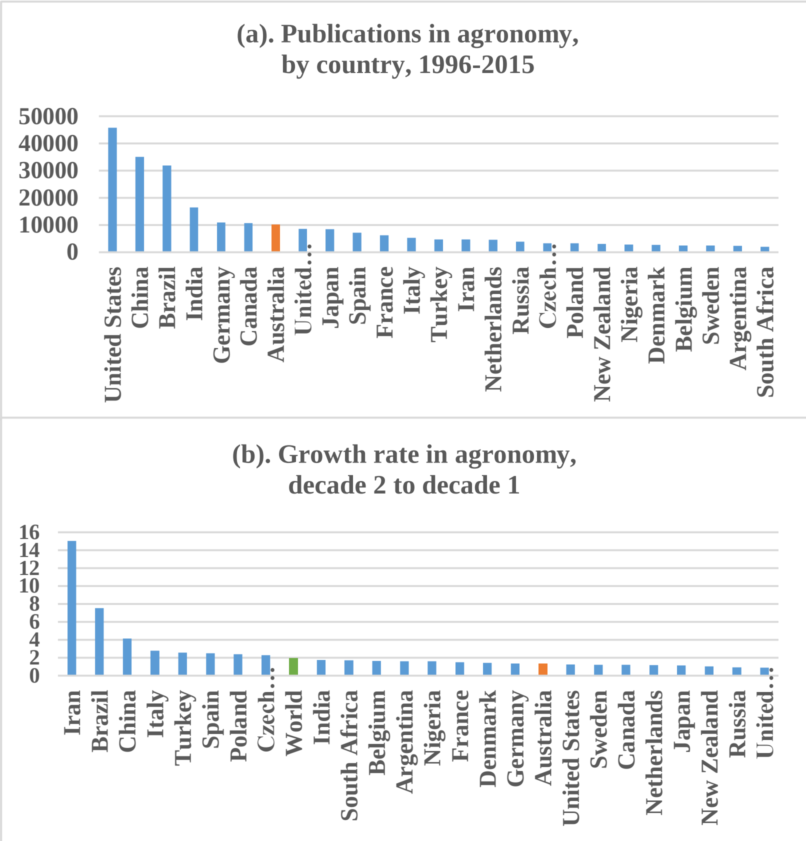

Figure 8. (a) Publication numbers in agronomy by country and (b) growth rate in publications by country from decade 1 to decade 2, for the period 1996-2005 (ACDA unpublished)

Over the 2-decade period Australian agronomic research has performed well, ranking 7th in publication number (Figure 8a), but an analysis of the growth in performance in the second decade relative to the first decade shows that there is a clear drop off in performance relative to several other countries (Figure 8b). It is recognised that some countries, *e.g.* Iran, perform well in this scenario from a low base but, regardless, the data suggest that the international competition is expanding and challenging Australia's standing.

The value of the publications can be inferred from the number of citations the publications received. In this case the measure is relative citations, with the global average citation index being set to 1.0. The data (Figure 9) suggest that for Australian agronomy, research is considered above average over the period of the study with a consistently higher performance in the second decade. This may reflect more ready access due to the internet for citing authors, although all papers, globally are now readily accessible. More specifically, CSIRO compares more than favourably with noted international institutions such as INRA, USDA, UC Davis, Agriculture and AgriFood Canada and Wageningen and has a high proportion in the top 1% of cited papers.

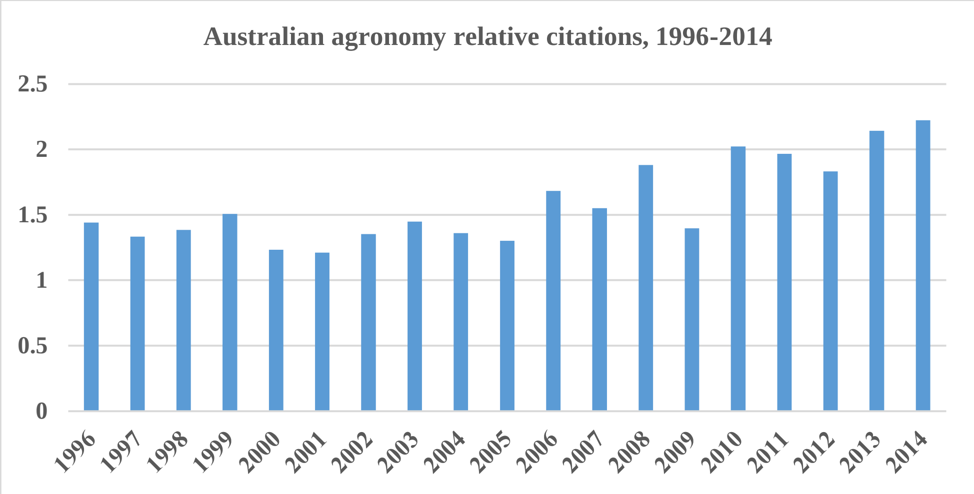

Figure 9. Relative citations (top) annually for Australian agronomy publications for the period 1996-2014, the world average being 1.0 (ACDA unpublished)

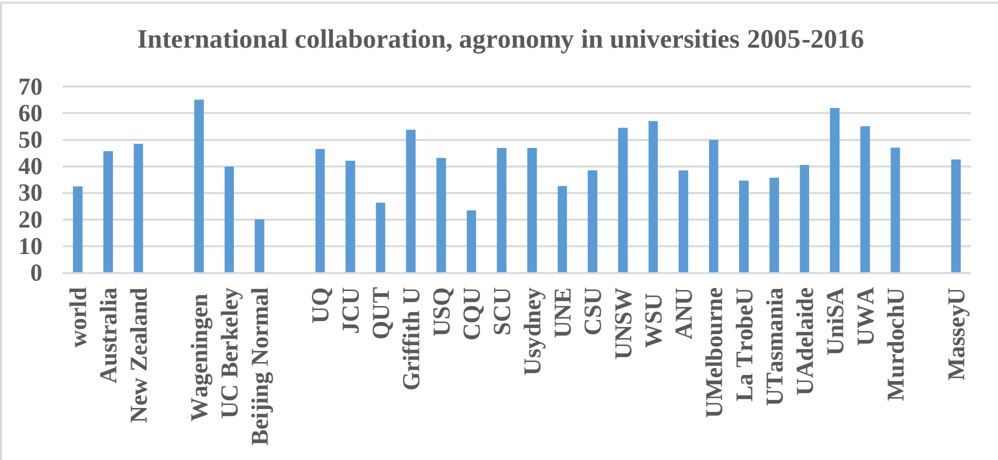

Figure 10. Proportion of Australian agronomy papers with international co-authors for publications in the period 2005-2016 (ACDA unpublished)

An increasingly used metric is international collaboration in research, and this is expected to increase. Figure 10 shows the extent of such collaboration for Australian universities as measured by joint authorship of papers. In general terms, for the period 2005-2016, 45% of Australian-authored papers have an international co-author, a proportion which is well above world average at 32%. International benchmark universities (*i.e*. Wageningen, UC Berkeley and Beijing Normal) have been included in the comparison showing Australia better than UC Berkeley and Beijing Normal but behind Wageningen University. Of the 20 Australian universities included in the study only two were lower than world average for citations over the period of study.

Research funding By all accounts above, Australian agronomy research has been performing well and in advance of many nations. But there are now many new international players in the game expending more on R&D than Australia. Data suggest that Australian government investment continues to decline in real terms and that seems unlikely to change. The major contribution by the Federal Government is the co-investment with industry levies as shown in Figure 11. The data show a steady increase in levy collections since the scheme began in 1990 and the increase matched in actual dollar terms by government until about 2006 when the co-investment flat-lined.

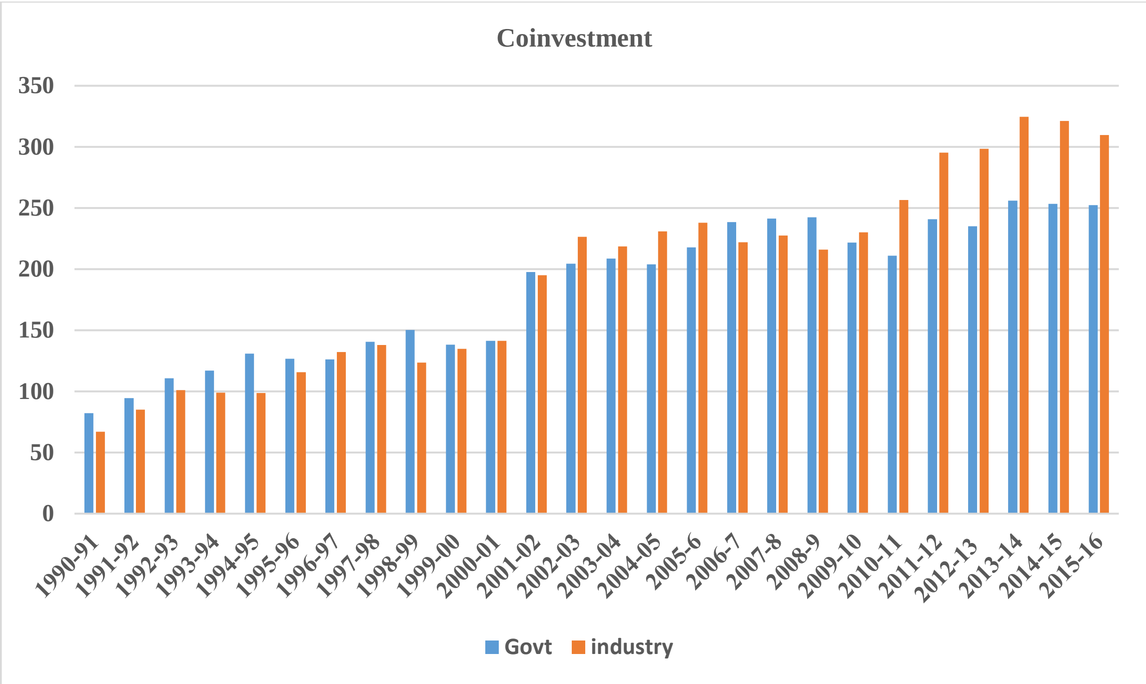

Figure 11. Annual industry levy collection and the 'matching' co-investment by the Australian government

The national government also funds other short-term schemes from time to time and its total commitment to R&D since 2005-06 has increased by around $150 million or nearly 20% to 2014-15. The main component of the growth now counted is to the private sector through R&D taxation incentives (Millist *et al.* 2017). At the same time State governments, who traditionally have been long-term investors in agricultural research, have reduced their commitments by around $100 million over the same period (see Figure 12). Universities coincidentally have increased their investment by around the same amount and now fund rural R&D to a greater extent than the State agencies.

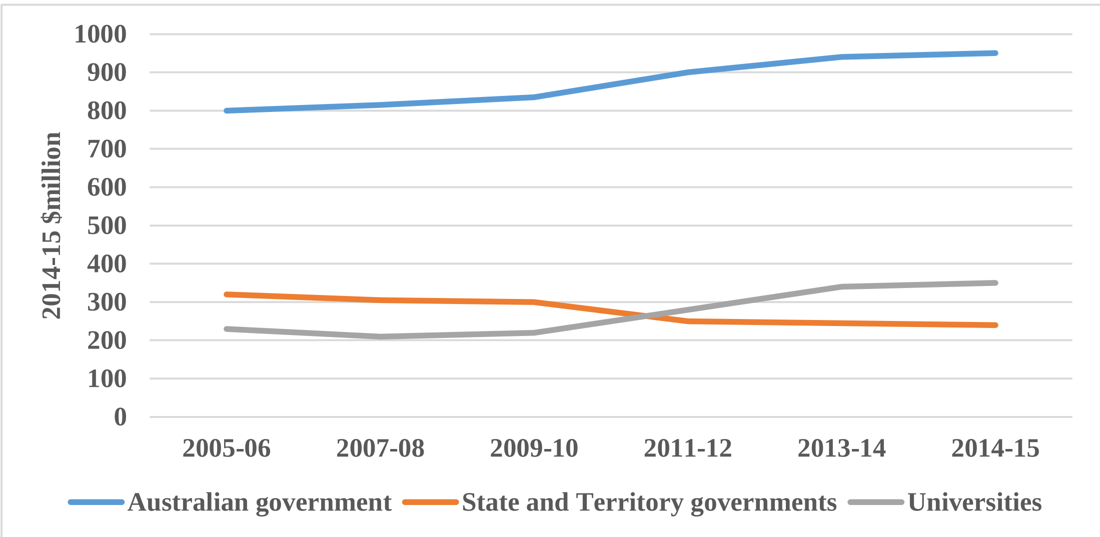

Figure 12. Public funding of agriculture R&D for the period 2005-06 to 2014-15 (adapted from Millist *et al.* 2017)

The public investment in agricultural R&D overall in Australia was considered by Sheng *et al*. (2011) and showed the flat-lining since the 1970s but a reduction in research intensity (*i.e.* the contribution in real terms after allowing for currency value decline, Figure 13).

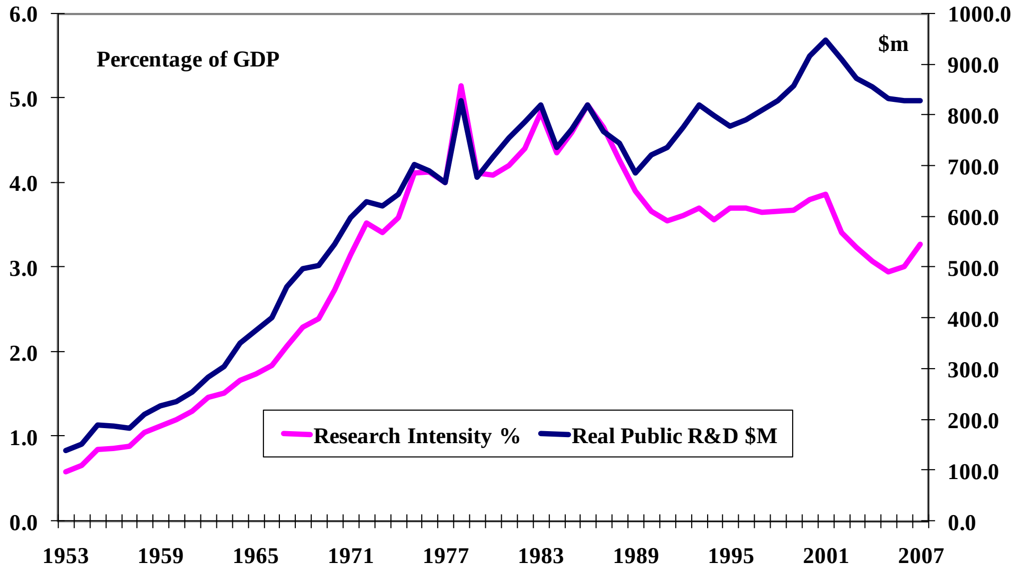

Figure 13. Real public investment and research intensity in Australian agricultural R&D (Sheng *et al*. 2011)

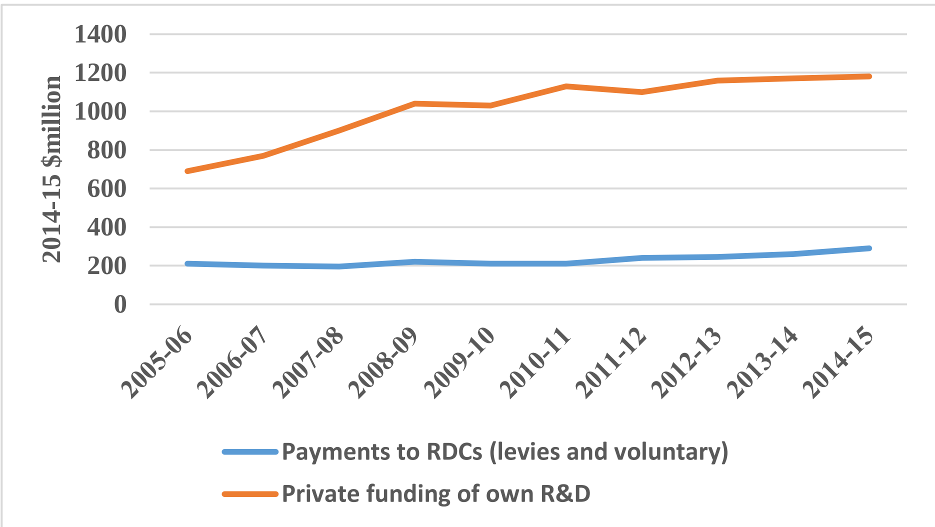

Figure 14. Payments by Government to research and development corporations associated with levies and private sector R&D investment against which taxation deductions are claimed (adapted from Millist *et al.* 2017)

The study by Millist *et al*. (2017) now allows the Government to claim, legitimately, that it is increasing its funding to R&D, thereby offsetting to some degree the issue of research intensity. Closer inspection of the increase suggests that the increase is in privately performed R&D rather than private investment in public R&D. This separation is starkly presented in Figure 14 and perhaps is a signal for future trends.

Research training The scientist pipeline traditionally comprised the training of higher degree research students (HDRs) through PhDs. Such HDRs undertake, under supervision, much of the transformative or 'blue sky' research that emanates from universities. That process has delivered high quality scientists into research organisations and industry over a long time. It is expected that research is an attractive career pathway, but over the last few decades that has not been the case. There are three major impediments to the supply of scientists in agriculture, including agronomy. These are:

- The failure to entice leading graduates into a research training pathway. This is in large part due to the discrepancy between financial conditions imposed on the HDR relative to those in industry. Currently the standard stipend for an HDR is ***less than half the salary*** of a graduate going straight from undergraduate studies into industry employment. There is no annual increment and no superannuation entitlement – nor is the taxation-free status of much value, particularly given that the scholars will be accumulating a fees debt to be repaid through taxation after graduation.
- The failure of the system to hold onto the HDRs until PhD completion due largely to the buoyant employment market and stipend inadequacy. This is shown in Figure 15 as strong completion rates for international students but a wastage rate of about one-third of domestic HDRs.
- The failure of industry, research organisations and research investors, including RDCs, to provide other than short term contracts to new scientists.

These scientist training conditions and the post-doctoral employment prospects are therefore clearly counter-productive to attracting the keenest minds into agricultural R&D.

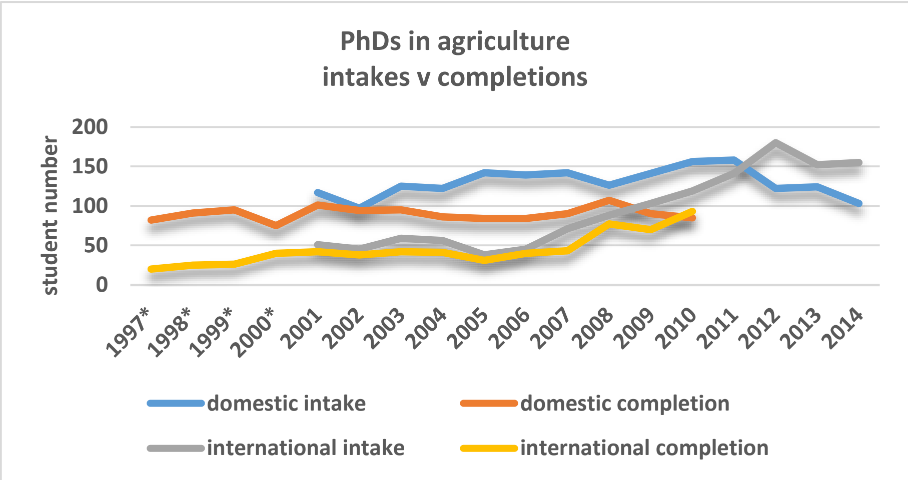

Figure 15. Comparison of intakes and completions of related cohorts of higher degree research scholars. Completions are offset by 4 years to link completions with intakes (Australian Academy of Science 2017)

The program of training PhDs in all disciplines has received much attention in recent years. Such specialised degrees are recognised for their strong scientific skills but are criticised by industry for their lack of business and inter-personal skills. Increasingly, the idea that HDRs should spend some time in industry is suggested to be of benefit to the innovation system and to the individual business and scholar (McGagh *et al*. 2016). It would also improve industry/university collaboration in Australia which currently resides towards the bottom of OECD comparators. This is applicable across the national innovation system and its application in agriculture would be restricted more likely to the secondary industry component than to the primary sector – yet the R&D undertaken is largely directed at the primary sector. The pressure for business experience takes time off those projects involving 'blue-sky studies' which may be compromised as a result. Cunninham *et al*. (2016) indicated that there is a disconnect between industry and universities. They record that "…Industry needs to start to understand that blue sky research is not a bad thing and universities need to start rewarding behaviour that industry finds valuable, instead of basing promotion only on publishing academic research".

While universities remain the awarding institutions for Master and Doctorate research awards, it is important to note that key agricultural research institutions, notably CSIRO and some state agencies, host a significant proportion of Australia's research scholars in their laboratories and field stations under co-supervision arrangements with a university. In some cases, scholars undertake their research in private company facilities in conjuction with the university. CSIRO in combination with Universities and Industry endeavours to bridge this gap with an Industry PhD scheme involving a period of industry placement (www.csiro.au/en/Careers/Studentships/Industry-PhD). Such collaborative arrangements provide for a more extended post-graduate experience and exemplify the industry/university model being proposed.

Future of agriculture R&D

R&D in agriculture in Australia has had several phases as described by Howard Partners (2018): mechanisation in the agrarian revolution of the 1700s; emergence of agricultural and associated sciences; and recently the impact of digital applications, data and analytics leading to 'disruption' of the industry and business models with support for AgTech and GeneTech start-ups through greater availability of risk capital. Ernst & Young (2019) indicate that Australian agriculture faces unprecedented change including:

- Changing global markets;
- Increasing international competition
- Technological disruption;
- Transforming industry structures;
- Climate variability and change;
- Water scarcity; and
- Increasing threats from pests and diseases.

While the Rural Research and Development Corporations (RDCs) are likely to continue their present functions, the push by the Federal Government towards innovation provides a perturbation that previously has not been experienced. Greater emphasis seems to be placed on entrepreneurship, risk-taking and cross-sectoral collaboration, characters that have previously been anathema to the operation of the RDCs. Greater focus will be on value-adding and will link increasingly with global connections ('connected innovation') and associated value chains: more priority will be given to innovation along the length of the supply chain. The 'buzz words' include agility, flexibility and responsiveness – their application will be a challenge to the existing R&D system. 'Start-ups' are the new currency as there is an expectation that strong commercialisation methodologies will be utilised to attract investment for their support. CSIRO provides such a scheme called "ON: accelerating innovation" to "get ideas out of the lab and into the world" (www.oninnovation.com.au). Hypothesis-based research, which has served the industry and science well, is under threat from the 'slick' technologies and the thrust towards innovation.

Howard Partners (2018) describe research as extending the knowledge base while innovation is about application of that knowledge to address problems or create opportunities within a business, environmental or social context. Much of the rhetoric in this space is silent on the first part – that of increasing the knowledge base, the 'blue-sky' activity, which has been struggling even in the existing system. The innovation paradigm is perhaps overdue, but it will impact on how things are done by changing the funding base, the culture of research and the attractiveness or otherwise of careers in this space. Unless care is taken it may run out of ideas to commercialise unless there is an underpinning of new knowledge discoveries.

Given then that agriculture is now part of the overall innovation thrust of government, it is worth contemplating just what that might mean. Innovation and Science Australia (2017) identified five urgent imperatives that needed to be addressed for the emerging innovation system (Figure 17) as:

- Education;
- Industry;
- Government;
- Research and Development; and
- Culture and Ambition.

None appear too onerous. ***Education*** in agriculture has been through a regeneration phase and most institutions are exploring the new digital age and what that involves. At the vocational education and training level new skills in digital technologies and robotics, for example, need to be fostered.

Industry perhaps is a challenge because of the 'disconnect' between production and some of the technologies; capabilities in some technical areas are lacking and internet limitations exist for a total embrace of data capture and utilisation.

Government will be applicable to agriculture as to other sectors but regulation hindrance, access to information and appropriate infrastructure seem to be blockages.

Research and Development has been previously canvassed but the lack of attractive support in research training and the uncertainty in research career prospects is of concern. Attracting sufficient investor support for the innovation agenda remains an unknown.

Culture and Ambition relate to 'national missions' and is perhaps the most challenging. Previously discussed is the lack of an overall strategy for agricultural research together with a culture of isolation and silo operation. It therefore appears that agriculture, and hence agronomy, could engage with the national innovation agenda as long as the incentives for doing so are clear.

Figure 16. Five imperatives for the Australian innovation, science and research system (Innovation and Science Australia 2017)

The future agronomist

International research (Cunningham *et al*. 2016) suggests that technology (*e.g*. machines, sensors, computers, robots) is displacing the lower skilled, repetitive and manual jobs in society. This has been happening over a long period of time in agriculture. However some jobs require "a high level of perception and manipulation where people can see and respond to circumstances in ways that computers and robots cannot" (Cunningham *et al*. 2016). The Decadal Plan for Agricultural Science (Australian Academy of Science 2017) defines agricultural science, not as a core discipline in its own right, but a confluence of many different scientific disciplines and endeavours – it is the integrator of advances in enabling sciences (Figure 18). That definition applies aptly to agronomists as discussed previously in Chapter 23. The range of disciplines is increasing rapidly with advances from informatics, big data, the Internet of Things, robotics, molecular biology and others described in this monograph. It is noted that farmers alone cannot be the font of all wisdom because of the complexity involved. In other industries companies have teams of personnel to address such complexity but farmers will need to outsource aspects of the business from time to time. The agronomist will be one of the experts sourced. Agronomists have played a leading role in creating the crop and pasture production systems of today, either through research findings or as a mentor to producers. The departmental extension agronomist played a significant part in implementation on farm until the 2000s but most cropping farmers now employ a private agronomic consultant, suggesting they perform a valuable role which is likely to continue. Both farmer and agronomist will need 'digital literacy' in order to be able to take advantage of technology, to engage with machinery and other suppliers and to source information. Agronomists, in turn, will need to engage with particular specialists as circumstances arise.

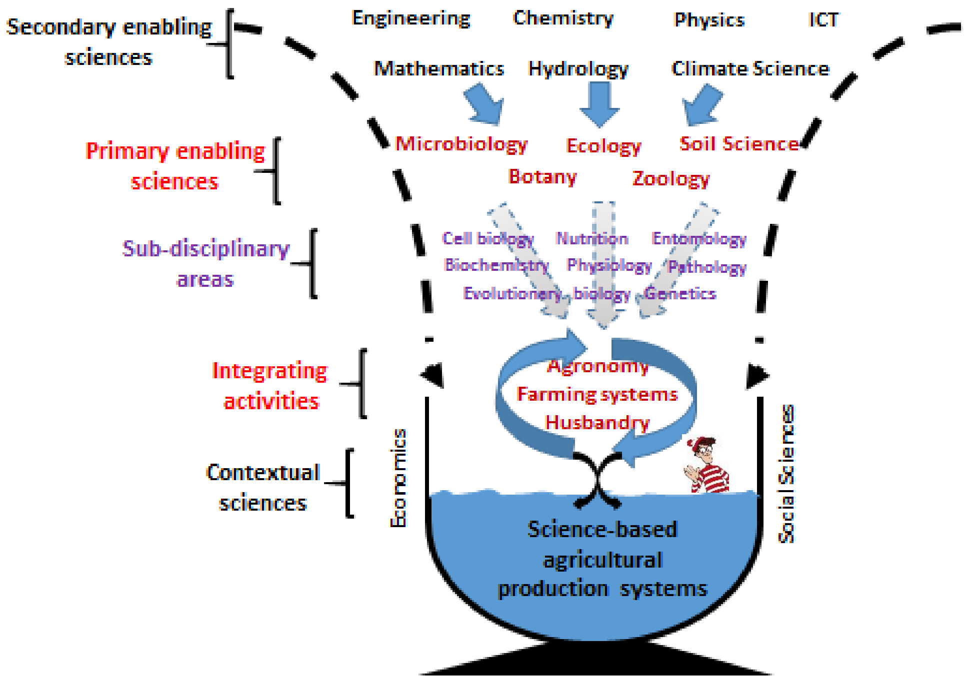

Figure 17. Inputs of disciplines and sub-disciplines for integration by agronomists towards sustainable agricultural production systems (Australian Academy of Science 2017)

This monograph provides strong evidence that the range of agronomists (*i.e*. research, academic, advisory, service) are needed for the tasks ahead. Clearly there is much research to do and the digitising of agronomy on farm and along the supply chains will need agronomic expertise. As integrators, agronomists have a leading role to play (see Chapter 23). The human dimension to agronomy is and will remain important and will not be easily automated because it is intuitive (Chapter 25). Automation will be very helpful in undertaking the tasks, but 'designers', *i.e*. the agronomists, will still be needed to determine what, when and how the tasks will be done.

It is also likely that the role of the agronomist will be further extended. The imperatives of minimising greenhouse gas emissions, ensuring land management meets community standards and satisfying increasingly stringent market requirements emphasise a role with greater environmental as well as production credentials. The digital and spatial capabilities of technology will provide increasing scrutiny on farm practices and environmental outcomes and this capability may assist in measuring the role of farmers in respect of ecosystem services, such as carbon capture. In that event, agronomists will play a pivotal role in ensuring that farmers capitalise on these opportunities, and thereby play a bigger role in mitigating risk in crop production.

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