TECHNICAL REPORT

# ACCELERATING PRECISION AGRICULTURE TO DECISION AGRICULTURE

## Enabling digital agriculture in Australia

This Project is supported by funding from the Rural R&D for Profit Program

Australian Government
Department of Agriculture and Water Resources

## Precision to Decision – Current and Future State of Agricultural Data for Digital Agriculture in Australia

S Barry, R Darnell, M Grundy, A Moore, M Robertson, J Brown, R Gaire, and George, A.

Australian Government
Cotton Research and Development Corporation

FRDC
AWI Australian Wool Innovation Limited
AMPC
Australian eggs
Australian Pork
LiveCorp
GRDC Grains Research & Development Corporation
Horticulture Innovation Australia
Dairy Australia
AgriFutures Australia
Forest & Wood Products Australia
SRA Sugar Research Australia
Wine Australia
mla Meat & Livestock Australia

Citation

Barry, S, Darnell R, Grundy M, Moore A, Robertson M, Brown J, Gaire R, George A (2017) Precision to Decision – Current and Future State of Agricultural Data for Digital Agriculture in Australia, CSIRO, Australia.

ISBN: 978-1-4863-0927-6 (Hard Copy) 978-1-4863-0928-3 (Electronic)



The project that delivered this report is led by the Cotton Research and Development Corporation and is jointly funded by the Department of Agriculture and Water Resources Rural Research and Development (R&D) for Profit Program and all 15 Rural Development Corporations.

**Acknowledgements**

The authors acknowledge the valuable contributions of Michele Barson (Agriculture & Water Resources), Peter Caccetta (CSIRO), Steven Crimp (BoM), Randall Donohue (CSIRO), Juan Guerschman (CSIRO), Alistair Hawksford (BoM), Alex Held (CSIRO), Emma Jakku (CSIRO), David Lemon (CSIRO), George Matthews (CSIRO), Neil McKenzie (CSIRO), Anthony Ringrose-Voase (CSIRO), Ross Searle (CSIRO), Rob Bramley (CSIRO) and Peter Wilson (CSIRO).

# 1 Executive Summary

## 1.1 General recommendations

This project used workshops and interviews with key stakeholders to identify which datasets and decision-support tools were currently being used across different agriculture sectors and explore where future investment opportunities may exist. Based on these interviews we identified five main cross-sectoral data types that warranted further analysis. These were soils, weather, imagery, land use and property boundaries. For each of these data types we have documented the key existing datasets, discussed the trends and opportunities and made recommendations about a desired future state.

A key finding from this study is that thinking purely in terms of data is anachronistic. While data will always be the foundation of information products, digital technologies and advanced analytics will facilitate a much broader suite of services and products.

A key question is what further investment in data and services needs to be made to facilitate full uptake of decision agriculture. Economic analysis by the Australian Farm Institute (AFI)[1] has found that there is significant value to be gained by full implementation of decision agriculture ($19.1Bn) and that, averaged over sectors, 70% of this value relies on publicly available or multiple datasets.

What we have concluded from the interviews and workshops is that the lack of data and associated knowledge is a significant impediment to new digital businesses entering this market. Acquiring data can be costly and the sales and commercialisation path may be uncertain. Thus, the risk of these investments and the competitive opportunities for the alternate use of this capital means that companies may not invest. Hence, we conclude there is a clear case for targeted investment in foundational information, data and services to increase the pool of potential vendors in the market.

There are other arguments for public investment in this data. An inherent feature of cross-sectoral data is that there are diffuse beneficiaries from its collection and exploitation. This is potentially an advantage, in the sense that there can possibly be greater returns from investment. But it can also be a disadvantage, as no one sector gets sufficient value to fund an entire program. The lack of a framework for shared investment and ambiguity around relative values is a significant impediment to coordinated action.

In reviewing cross-sectoral data it has become apparent how haphazard the development of data and knowledge assets has been in some cases. While the value of information and knowledge about Australia has been recognised, there has not been a fully coordinated strategy around its prioritisation and collection. The current data and assets reflect needs, decisions and priorities that have changed over time. But whether this is efficient going

[1] Precision to Decision – Analysis of the Economic Benefits and Strategies for Delivery of Decision Agriculture 2017, Australian Farm Institute

forward, as the opportunities for predictive analytics in the agricultural sector increase, is questionable. We thus recommend that there is a strategic plan around cross-sectoral data assets, and that the draft version of this plan come from this document. We recommend:

1. *A national agriculture data infrastructure should be developed, based on a strategic plan rather than the result of episodic and haphazard development. The plan should be a living document that identifies the needs and the pathways to achieving them, such as public, public–private, and private investment. The plan should be regularly reviewed to assess its progress and update its goals to reflect new needs, knowledge and opportunities.*

One of the initial premises of this project was that gaps in publicly available data were a significant impediment to technologies developed in the North American market spilling over into the Australian market. While our interviews and research did suggest that more publicly available data would facilitate more business opportunities there was no single example where the absence of data was the only impediment to market entry. Given this, we still conclude that the lack of key information and knowledge is a contributing barrier to entry. We recommend:

2. *Targeted investment to produce foundational data and models relevant to Australian systems is needed for the development of data-driven decision-support systems, particularly where lack of this information is a barrier to entry. Sustained, targeted investment in analytic capabilities for Australian agriculture/fisheries/forestry is an essential requirement to deliver the value of cross-sectoral data.*

Another key finding from this project is that while the existence of data and knowledge is necessary to facilitate decision agriculture, it is not sufficient. There is substantial work that needs to be done to develop analysis-ready data. Not doing this is a significant barrier and condemns the data to being accessible only to a small set of experts.

Given that appropriate products exist, it is still necessary that data are findable and trustworthy. Through this project we have identified that simple portals containing links to large numbers of datasets of varying quality and spatial and temporal extent are a limited resource for new participants in the digital agriculture sector. The data also need to be accessible in standard formats that allow reuse and integration with sector-specific information. We recommend:

3. *Investment is needed to fully leverage the existing data holdings. While much data relevant to digital agriculture exist, the data are often in formats that require considerable expertise in processing and analysis to deploy operationally. This is a significant barrier to use of the data. There is a clear need to go beyond simple data portals that aggregate raw information, and to develop information systems that produce 'ready to go' data which can be used directly in analysis.*

4. *Rural development corporations (RDCs) should combine to advocate for FAIR (findable, accessible, interoperable and reusable) storage and dissemination of datasets that are valuable across the rural sector and that are also widely used in other industries. Examples of classes of data where RDCs should actively advocate for secure and FAIR access include: (i) satellite imagery (especially via Geoscience Australia and particularly to ensure reliable access to the next generation of public-sector satellites such as*

*Sentinel-1 and Sentinel-2); (ii) historical and forecast climate information; and (iii) improved monitoring of land use.*

The sharing of data between organisations and individuals is one of the key opportunities opened up by digital technologies, but it is also one of the most challenging. Shared data can be used in a variety of ways. The ability to gain additional value from private investments occurring in data collection should not be underestimated, but neither should the current lack of infrastructure and proven business models to support this. This is an immediate priority. We recommend:

5. *A platform or platforms are needed for owners and users of agricultural data to exchange, market and value-add data for a variety of end purposes. We recommend exploring the feasibility of an industry-good platform, with appropriate business model, that could catalyse data exchange, along with appropriate protocols around use and rights of owners and users.*

Data that is of importance to the agriculture sector is often of interest more broadly. Obvious examples are weather and remote-sensing information. Broader alliances need to be formed in these cases. Where agriculture is the primary beneficiary of investment, RDCs should lead these discussions. We recommend:

6. *RDCs should build partnerships with other beneficiaries to leverage investments in data where possible. Where no other beneficiaries exist, there needs to be commitment to the acquisition, provision and dissemination on topic areas where the rural sector are the primary users. An example of a class of data on which RDCs should focus their investment effort is the acquisition of functionally relevant soils data, especially beyond the broadacre cropping zone.*

The new opportunities being facilitated by digital technology rely on a range of skills. To participate fully, people need knowledge of digital technologies to understand opportunities. They need knowledge of agriculture to understand the true value proposition of information and services. And, they need to understand the opportunities that digital technologies will provide for business-process innovation across the sector. While there is a pool of people with some or all of these areas of expertise, that pool is not large enough to harvest the coming opportunities. We recommend:

7. *As a matter of urgency, changes to university training must be devised to ensure a future supply of agricultural data scientists. There is a foreseeable need, both in the R&D sector and in industry, for people with digital skills who also understand the agricultural sector. Evidence indicates that the Australian university system is not producing sufficient agronomists with the required skills and that current incentives to change this situation are insufficient.*

## 1.2 Data-specific recommendations

### 1.2.1 **Soils**

The soil is one of the primary focus areas for farming decisions. Knowledge of key soil characteristics is a foundation for achieving sustained production and productive capacity. However, without an adequate information base, the distribution and characteristics of soils as they impinge on farming-system decisions are neither obvious nor easy to monitor. As a consequence, better farming-system decisions require a diagnostic system both to identify the most appropriate settings for management and to monitor how soils (and the soil–plant system) are functioning. Three important components of the diagnostic system are:

- an understanding of how soils vary across the paddock, farm and in the context of the broader landscape (e.g. expressed in digital maps of soil properties and functional types)
- an ability to detect and interpret soil changes with time (e.g. availability of nutrients, pH, organic carbon, plant-available water)
- a capacity to forecast the likely state of soils and impacts on the production system under the available land management options and experienced weather and climates (e.g. through the use of simulation models).

An effective soil-information system would provide the relevant information (function, scale, timeliness) to increase agricultural efficiency, reduce risk and raise productivity.

We recommend:

8. *An Australian Soil Information Facility based on new business models to support the on-going collection, sharing and value-adding to soil information across state agencies, CSIRO, universities, and agribusiness should be established. The quality and density of digital soil information that can be readily used by public and private-sector players is limiting the development of digital agriculture products and services. While great strides have been made in the development of the Soil and Landscape Grid of Australia and the Australian Soil Information System, the data assets available are still limiting to innovation. We also recommend the complementary development of a private soil data community that incentivises and rewards the collection, use and improvement of soil data held in private hands (e.g. data from farmers' soil test results, fertiliser companies, geophysical surveys collected by agronomists). Both these initiatives will build towards the continual improvement and subsequent dissemination of fine-scale soil products like the Soil and Landscape Grid of Australia.*

### 1.2.2 **Weather**

There are three opportunities to improve Australian weather data. One is to find ways of harnessing the private investment in sensors. Increasingly farmers, either individually or via advisors and platforms, will invest in sensors such as weather stations or soil moisture probes as part of digital agriculture solutions. There is a significant opportunity to leverage this investment to develop better weather products. The second opportunity is to develop products that are 'ready to go' in the sense that they are tailored directly to agricultural applications and can be seamlessly incorporated into decision-support systems. The third opportunity is to improve the skill of weather and climate forecasts to enhance our resilience in agriculture. Key actions where the most impact could likely be realised are:

i. improved measurements, assessments and predictions of extreme events such as drought, heatwaves, hail or frost
ii. increased understanding of the climate thresholds and tolerances of our vulnerable commodities (e.g. heat stress in dairy cattle; wheat yields under increasing temperature and decreasing rain; humidity/rainfall near picking times for fruit and vegetables)

iii. increased skill in making multi-week forecasts (10 days to 1 month) and an exploration of who can best use them, along with an integration of these forecasts into the existing decision-tool space

iv. forecasts of climate at time horizons of 6–24 months for strategic on-farm decisions such as stocking rates and investments.

We therefore make the following recommendations:

9. *A seamless mechanism is needed to draw upon the vast array of sensors and informally collected weather data to develop locally relevant forecasts and observations. The scale mismatch between climate and weather model forecasts and the required paddock-scale knowledge is an ongoing challenge. Even with increasing resolution in models, we need to focus on techniques to calibrate the forecasts with on-farm meteorological records to truly gain the value of the forecasts at the individual-paddock scale.*

10. *Agricultural organisations should explore opportunities to work with the Bureau of Meteorology (BoM) and other data providers to 'translate' weather and climate information into bespoke products with more context-relevant terms for end users. Weather and climate information (short-term and long-term outlooks) is often communicated to the farming and advisory communities in meteorological terms, but not in practical, actionable ways that directly relate to individual on-farm decision making.*

11. *There should be an investigation to identify domains that could use sub-seasonal forecasts to alter their decision-making processes and find ways to implement this data into existing decision-support tools. Sub-seasonal climate forecasts (1 week to 1 month) are an emerging product in the meteorological arena. Their potential benefits have not yet been realised in decision-support tools.*

### 1.2.3 **Remotely sensed imagery**

Remotely sensed (RS) information products have the capacity to generate geographically extensive and cost-effective data and will be crucial to the full implementation of digital agriculture. There are also significant developments in sensors and platforms that will create significant new data streams. History shows that significant investment needs to occur to convert this opportunity into information products and services that can be used reliably and extensively across agricultural industries.

Investment in this information ecosystem will be a critical step into the future. This means research into, in particular:

- the evaluation of new sensing systems, the information they may provide, and the value that they offer to the agricultural industry
- the reception, storage and workflows of the data such that near-real time and predictive capacity can be utilised (i.e. timeliness of results)
- how to optimise the integration/assimilation of multiple RS data streams, and how to optimise the integration/assimilation of these with proximal sensors, sensor networks, personal technology, and data analytics
- the predictive modelling capacity that is built around the information ecosystem.

We therefore recommend:

12. *Revamping how publicly available imagery is made available should be considered. RS imagery has been and will be increasingly used in digital agriculture applications. However, RS imagery that is appropriately processed and timely is not easily accessible and interpretable to those wishing to use it for digital applications. Moreover, the coverage, frequency, access to and ease of use of the emerging satellite layers (e.g. Sentinel) need to be assessed and industry-wide platforms created for these layers, and integrations of them to be accessed and used. There is also a need to develop optimal metrics for prediction in Australian systems.*

### 1.2.4 **Land use data**

Land use data is useful for a wide range of purposes. It can support industry biosecurity planning, surveillance and response. It can provide better industry planning, development of infrastructure and targeting of third-party products and services. It can allow better regional planning and policies by government. If it is collected in real time it can support better crop forecasting and industry logistics.

There are significant opportunities to improve land use information. New streams of digital data from satellites, administrative sources and agriculture platforms can potentially provide a much richer information base that can be assimilated to produce more accurate and timely products. We recommend:

13. *The existing Australian Collaborative Land Use and Management Program (ACLUMP) partnership should be leveraged with new data streams from remote sensing, government and industry to develop more timely and accurate products with multiple end uses. Improved land use data have a wide range of potential uses such as biosecurity management and industry planning. There are significant opportunities to improve on existing products to make them more timely and accurate by using new remote sensing, administrative and industry data streams and analytics.*

### 1.2.5 **Property boundaries**

Legal property boundary information is a core government function and is already well developed and has strong legislative requirements.

There is no register linking parcels, properties and legal ownership. This could be useful to automatically integrate remote monitoring to properties, and allow better understanding of industry structure. We note that information about physical property boundaries will increasingly be collected as part of digital agriculture. The value in sharing this information is still to be determined.

# Contents

# Figures



# Tables

# 2 Introduction

Digital technologies are currently underpinning revolutions in business and society. In particular, digital technologies have driven major efficiency gains in almost all industries since the late 1970s. Digital technologies, and the complex infrastructures such as the Internet created by them, have opened up entirely new business models and opportunities. Whole industries can and have been disrupted. New industries can arise where none existed before.

The power and reach of digital corporations is clear. The top five US companies based on market capitalisation are technology companies – Apple, Alphabet, Microsoft, Amazon and Facebook. Companies such as Uber who provide a platform for ride-sharing services can enter local markets in contravention of existing regulation and effectively force change that is advantageous to them. A company such as Alphabet (i.e. Google) has access to staggering amounts of information both in terms of total documents and the underlying knowledge of people's behaviours and browsing activities.

Agricultural industries have long been innovators in the use of technology. Mechanisation, industrial production of fertilisers and pesticides, and dramatic improvements in crop varieties and breeds have led to substantial productivity improvements over the previous century. Digital technologies have been part of this increase in efficiency. For example, computers have been used to develop models to predict yield based on management choices that can be used to aid decision making. Global positioning systems (GPS) have been used in broadacre cropping since the 1990s to implement auto-steer systems in machinery. Farm management is routinely performed via spreadsheets and databases. The advent of GPS and yield monitors heralded the beginnings of precision agriculture. The core idea of precision agriculture was that collection and analysis of spatial information would allow more efficient production. More recently there has been heightened interest and associated hype around digital agriculture. This is being driven by a range of forces and was initially centred in the US. The primary opportunities have arisen by the confluence of a number of factors. First, the cost of collecting data is falling as new technology and sensors become available. Machinery is increasingly 'smart' and is sensorised and able to communicate digitally. Second, computing platforms and services such as the cloud are becoming ubiquitous, providing natural platforms with both the required storage and the computational power to deliver digital agriculture services. Third, existing agricultural companies are going digital to ensure their future relevance and to open new data streams to exploit in order to develop new products and services. Fourth, there is a range of successful digital business models that are being imported into the agriculture space. For example, Google has shown that having access to data about users can provide information to sell to advertisers, as well as information to tailor the experience to individual users. Some digital agriculture companies are trying to replicate this model. Other companies are trying to implement decision-support techniques in agriculture that are well developed in business analytics (for example dashboards) to provide situational awareness to managers.

These factors combine with the relative lack of maturity of the industry to produce a complex range of products in the market. Some products are centred on a new sensor technology, such as drones. Some are centred on providing services to support information platforms using cloud services. Some are trying to integrate information to support more refined decision making.

Some are trying to setup more complex business models by developing forums to bring together producers and suppliers. And some are doing a mixture of all these things. There are also a variety of start-ups in this space that will pivot their business models to attempt to find a profitable configuration. So, the diversity can be bewildering. A key event in the development of digital agriculture was Monsanto's buyout of The Climate Corporation for USD$930 million. The Climate Corporation, a data-mining company, underwrites weather insurance for farmers thereby protecting the USD$3 trillion global agriculture industry from extreme weather events[2]; it does this by ingesting extensive freely available public weather and Earth observation open data gathered by the US Landsat satellite. It takes the eight years' worth of soil and precipitation records for each of the 29 million farm fields in the US to generate 10 trillion simulation data points. This amounts to processing 50 terabytes of weather information every day.

There are numerous other examples. John Deere has said precision services and its 'intelligent solutions group' would be a major contributor to doubling its size from a USD$25 billion company in 2010 to a USD$50 billion company by 2018. Recently Amazon paid USD$13.7 billion to buy Whole Foods Market in the US. Whole Foods Market aspires to several standards for many of their products; sustainability in seafood, antibiotics in meat, and pesticides in vegetables among others. To validate these claims, data on specific items need to be kept right through the production chain.

There is still considerable debate about the real potential business value of digital products and services in agriculture. It could be argued that many offerings are speculative. In addition, the platforms and technologies are only now maturing so the industry has not consolidated. As companies seek market share they may trade current profitability for future earnings. For example, the ride-sharing service Uber is still valued at around USD$70billion while in the last 3 months of 2016 alone, the company lost USD$991 million.[3]

Many of the systems and platforms in digital agriculture have been developed in the US. This reflects the larger US market, the location of the major agribusinesses in that market and the bigger pool of venture capital. Many of the major platforms are in the process of establishing Australian operations and/or franchises. In a comprehensive report, the Australian Farm Institute (AFI) identified a number of potential challenges to the existing US technologies being applied in Australia (Perret et al*.* 2017). In particular they noted that the lack of publicly available soil and weather data meant that established approaches in the US corn and soybean industries would not directly transfer to the Australian market. The US has publicly available detailed soil and weather information that Australia lacks.

Australian agriculture is at an important juncture. Digital technologies are disrupting existing business models and transforming all aspects of the Australian and world economy. There is an existing and successful agricultural technology and advisory sector in Australia but the pool of resources to develop new technology is limited. There are major investments in new digital

[2] Jeni Tennison Director of Open Addresses UK and Technical Director of the Open Data Institute, 'The Economic Impact of Open Data: What Do We Already Know?', *HuffPost UK*, http://www.huffingtonpost.co.uk/jeni-tennison/economic-impact-of-open-data_b_8434234.html.

[3] Chris Mills, 'Uber Can't Stop Losing Money', *BGR*, April 14, 2017, http://bgr.com/2017/04/14/uber-2016-profit-loss-financials/.

agriculture platforms occurring internationally. The challenge is to ensure that the potential efficiency gains from digital agriculture are achieved.

That Australia could miss out on the benefits of digital technologies because of gaps and deficiencies in our data infrastructure is a significant concern. This report explores these issues. In particular, it considers whether the lack of available data in Australia will limit the benefit that can be derived from the adoption of digital technologies. It surveys currently available data sources and decision-support tools. Based on interviews with producers and industry representatives as well as independent research, it considers where future investment may give economic returns. The review will serve as a resource for producers, policy makers and commercial technology suppliers to guide their decisions for future investment and planning.

Whether Australia can mitigate the risks and grasp the opportunities depends on a number of issues. At the highest level there needs to be an assessment of whether tools and platforms developed for other markets will be fit for purpose for Australian enterprises. Australian farming systems have similarities and differences to those overseas. A key policy question is whether these differences will lead to significant barriers or delays to entry and whether this risk can be mitigated in some way.

Where existing platforms are fit for purpose, there is opportunity to leverage off international investments to access cutting-edge technology developed in other markets. To allow this leverage to happen requires understanding what potential barriers exist. In particular, are there gaps in our data and knowledge holdings and information infrastructure that will make the Australian market less attractive for investment and development? Where products do not exist, there needs to be opportunities, and in particular no barriers, for Australian companies to develop appropriate technologies.

All industry sectors and research and development corporations will need to make these assessments taking into account the different business models, production systems and technology providers. But there will also be opportunities for cross-sectoral investment and strategy around data. This report considers these cross-sectoral issues and is a component of a broader project examining issues around privacy, ownership, architecture and availability of data in Australian agriculture.

The report is organised as follows. Section 3 defines the scope and Section 4 the methodology followed for this project. Findings from the workshops are reported in Section 5. In Section 6 and Section 7, we summarise the current and future state of agricultural data and online datasets, respectively, in terms of the five focus areas (soils, weather and climate, remote sensing imagery, land use and property boundaries). The complete data and decision-tool registers can be accessed at p2d.csiro.au. The role of decision-support tools in agriculture is presented in Section 8. In Section 9, we present a register of common software tools for turning agricultural data into a decision. In Section 10, we discuss our recommendations in the light of the entire report. The report concludes with Appendices containing the detailed findings from the workshops and a Glossary.

# 3 Scope

Digital agriculture is a diverse field across both multiple agricultural industry sectors and associated product and services supply chains. In addition, the systems and business models used potentially vary across the industries. Thus, while there are multiple potential opportunities across this business landscape, reviewing them all is a significant undertaking and is much better suited to industry-specific analysis. This report focuses on cross-sectoral, publicly available data and decision tools relevant to Australian producers. The term 'sector' here means the primary natural resource sectors, agriculture, fisheries and forestry and the industries within these. We have further grouped agricultural industries into cropping and livestock. This grouping focuses attention on the datasets common to the industries and acts as a guide for prioritising recommendations.

We consider datasets available and accessible for and relevant to producers and service providers. This includes data and tools provided by government or statutory authorities within Australia as well as datasets and tools provided by commercial service providers. The restriction of access to commercial products has limited the information available on some of these products. The information from these sites has been presented as reported by the company.

The scope is also limited to considering data and decision tools that impact on activities directly related to production. We note that there is some ambiguity in this as a key opportunity of digital agriculture is to increase information flow though the value chain. This information can then drive on-farm decisions. Given this, we believe that the primary cross-sectorial opportunities will be in common information architectures rather than in shared decision tools and data.

Many websites, such as the Biosecurity Portal, provide a lot of information as fact sheets and pdf files. We have not included these except where specific data and tools are provided.

The findings and recommendations in this report are based on discussions with industry experts, service providers and producers during interviews and producer workshops. Ethics approval was obtained on the basis that the information was anonymised.

# 4 Methodology

The primary data collection process of this project was based on a series of interviews with people involved in Australian agriculture. This was done based on a number of different avenues. First, we attended eight regional workshops across multiple agricultural sectors and locations in Australia (details below). These workshops varied in their composition depending on the industry but typically involved primary producers, agronomists and advisors. In some cases, government scientists, academics, and digital platform consultants and banking officials also attended. These workshops followed a structured format where participants were interviewed about current use of digital technologies and asked where they thought there was significant value in further adoption.

A second avenue of activity was targeted at the fifteen research and development corporations. We conducted interviews with representatives from these. The third avenue was a workshop with technology companies that are active in Australian agriculture. These companies included those providing both hardware-based and software-based solutions. This information was supplemented by interviewing additional product representatives. The fourth avenue was through the engagement of agricultural data experts to explore existing data holdings and to discuss high value opportunities to pursue.

## 4.1 Workshops

Eight workshops were held in various regional locations in Australia (see Appendix A.1). A set of questions was constructed to: (i) uncover the steps in a producer's decision-making pipeline; (ii) identify the datasets and decision tools that are in use by producers; and (iii) identify the gaps in a producer's decision pipeline. The participants were placed into one of 4 groups to facilitate open contribution to the data-gathering exercise. After the fourth workshop, the process was altered slightly. A more 'global café' approach was adopted. Here, members of the research team led groups of attendees through the above process. The change in format was necessitated by the monopolisation of answers by some participants and also to better capture the opinions of all workshop participants. The workshop schedule is shown in Table 1.

**Table 1: Industry, location and date of workshops that were run to understand the current and future data needs of producers**

| WORKSHOP | INDUSTRY | LOCATION | DATE |
|---|---|---|---|
| **1** | Horticulture/vegetable | Gatton, QLD | 5 December 2016 |
| **2** | Horticulture, sugar | Townsville, QLD | 1 March 2017 |
| **3** | Meat, grains, cotton | Tamworth, NSW | 2 March 2017 |
| **4** | Grains, wool | Northam, WA | 16 March 2017 |
| **5** | Pork, grains, rice | Wagga Wagga, NSW | 28 March 2017 |
| **6** | Dairy | Tatura, VIC | 29 March 2017 |
| **7** | Forestry | Launceston, TAS | 30 March 2017 |
| **8** | Grapes, wine | Tanunda, SA | 27 April 2017 |

## 4.2 Building the data and decision-tool registers

In building the data register and the decision-tool register, we adopted a bottom-up and top-down approach. The steps we followed were:

- Step 1 (bottom-up): hold a series of workshops and interviews (described above) to identify the core datasets and decision tools
- Step 2 (bottom-up): use the findings from the workshops/interviews to expand the search by conducting a desktop review with Google – this search used keywords such as agricultural data/analytics/decision/tools/software/platforms to form a more complete list of agricultural datasets and tools

- Step 3 (top-down): search data catalogue sites such as data.gov.au, portal.geoscience.gov.au, poama.bom.gov.au, portal.aodn.org.au, data.aurin.org.au and the individual state government data repositories for agricultural datasets
- Step 4 (top-down): search the OzNome (https://research.csiro.au/oznome/) catalogue for agricultural datasets and decision tools not yet identified from the previous steps – the OzNome project is a new initiative to connect information across Australia by harvesting metadata from publicly available data sites
- Step 5 (top-down): use a panel of domain experts to critique relevance of register entries.

As we undertook the above process, the challenges of forming the registers became apparent. Only a very limited set of datasets and decision tools were revealed through the workshops and interviews (step 1). In contrast, steps 2–4 uncovered a multitude of datasets of varying quality and relevance. The datasets and decision tools do not come with a measure of their importance to the industry; hence, it was necessary to enlist the help of domain experts (step 5) to manually cull the list of datasets and tools to a meaningful subset.

# 5 Workshop findings

While the workshops were targeted at exploring the use of data and decision tools with the aim of identifying cross-sectoral opportunities, a number of broader observations can be made. The first point to note is that while there is great awareness of the potential of digital agriculture, development of the skills and products needed to exploit it is only beginning. There are fundamental issues with data processing and interoperability between systems. While individual sensor systems such as soil moisture or yield and the associated analytics to process them are becoming more commonplace, there is still significant work needed to develop integrated solutions. There is a near-universal understanding that more and more data is become available to make decisions; the problem is framed in terms of how to analyse these streams to take value from this data. This is currently challenging due to a limited pool of people with the required skills and the very basic interoperability between systems.

The second point to note is that there is currently a range of successful technology and advisory companies servicing Australian agriculture. International companies are developing presences in Australia, either independently or in partnership with Australian companies. While it is early days in the development of a fully digital industry there is significant activity that can be potentially harnessed to develop products suitable for the Australian market.

The third point is the sheer diversity of potential opportunities for the use of data. Discussions at the workshops ranged across a wide variety of issues. There was obviously a lot of interest in on-farm learning about the relationships between inputs and production information. But there was also significant interest in opportunities to benchmark, to use data from the supply chain to improve products and to use systems to reduce compliance costs and reporting burdens. A summary of the workshop responses is given in Appendix A.1.

A somewhat surprising conclusion from the workshops was the lack of coherent views. Opinion was divided about the extent that available information and knowledge is limiting the uptake of digital technologies. This is also complicated by service providers offering integrated services that incorporate both data collection and analysis. This variation in opinion was also reflected around data sharing. While most people could see the value in sharing data, the model that would be socially, legally, politically and economically feasible and acceptable remains unclear.

This lack of clear direction from the workshops also manifested itself in the identification of high value case studies. The project was designed to use these case studies as a filter to identify common issues across sectors. It is perhaps understandable that participants at the workshops found it challenging to consider a future that does not yet exist. Additionally, it is clear that where high value opportunities exist they are already being exploited. This is not to say that there are not high value opportunities. Rather, that in hindsight the workshop methodology was not the best vehicle to explore them. Considering a world with pervasive data is still on the horizon.

Given these limitations the process did identify five key areas of cross-sectoral data. These were soils, weather and climate, remote sensing imagery, land use, and property boundaries. While improved market information (i.e. prices etc.) was also mentioned, and would provide significant value, it was declared to be out of scope as it was still related to particular sectors.

# 6 Cross-sectoral data: current and future

The collection and dissemination of agriculturally relevant data has a long history in Australia. For example, within months of the arrival of the First Fleet, Australia's first 'meteorologist', Lieutenant William Dawes, set up an astronomical observatory and commenced recording weather observations. In another early instance, ex-convict James Ruse, on the 'Experiment farm' recorded a yield of 8 bushels/acre of corn. As the colony matured, new data was needed to understand and develop the abundant natural resources.

The current data infrastructure in Australia reflects its history. Data has been collected at different times for different purposes. While all subject areas have seen some degree of consolidation they all reflect some level of evolution rather an overarching strategy. This reasonably reflects the realities of funding and history and is not a direct criticism. But it is useful to consider what may be needed in the future as opportunities to leverage its value increase. This section does this analysis. In the five key areas it outlines the class of data, the current state and emerging trends. It then considers a desired future state and discusses what needs to happen to get there.

# Case Study: On-farm Data Sharing

Taken, with permission, from Birchip Cropping Group 2017 report on Digital Inequality In Rural Areas

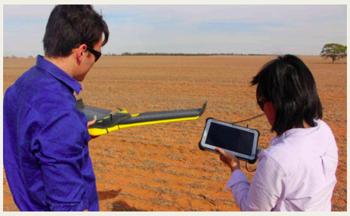
Australian farmers are becoming aware of the value that can be derived from the data they collect on their farms. With the advent of yield monitors, soil moisture sensors, weather stations, livestock weighing systems, and software packages for recording of farm operations, farmers are collecting larger volumes of data that they report they have difficulty in managing, analysing, and interpreting. In addition, there is additional value in pooling data to generate more detailed predictions or to use as benchmarking information.

There is a concern in some quarters about the lack of control or transparency about who may use their data and for what purposes. There are also concerns about the flow of value from the use of this data. In the US, farmers have responded to this challenge by participating in businesses that aggregate data from many farmers, providing back a value-added data product or service to individuals, such as yield benchmarking.

Courtesy Chris Sounness

To this end, some farmer groups in Australia have been exploring the technical possibilities and business structures that would allow them to aggregate data across many farms and provide services back to their members, as well as potentially a product for on-selling to 3rd parties with an interest in large industry-based datasets. One particular business structure being explored is that of a co-op, whereby farmer members contribute their data and agribusiness and research providers partner with the co-op to provide value adding to the data.

An example is the data co-op being developed by the Birchip Cropping Group. In this coop farmers can share data in a controlled way. Depending on the level of data provided, sharing will potentially provide access to regional benchmarking information, on farm yield investigation based on soil, climate, fertilizer and rotation information and analytics based soil mapping, all of which should improve profitability. To do this requires access and use of publicly available datasets such as climate, soils, and remote sensing. There will be challenges in dealing with harmonisation of farmer datasets that are held in different formats. Patchiness and variable quality will also be issues.



Taken, with permission, from Birchip Cropping Group 2017 report on Connectivity Capability Trust.

**Box 1: A case study of how on-farm data can be shared across farms and to the benefit of all**

There is a level of complexity in analysing the return on investment in data and whether this should be funded publicly or privately. We note that with cross-sectoral data this can be complex as there will be a large number of diffuse beneficiaries. While individual beneficiaries do not derive enough value to fund the data, in aggregate they do. Entry of commercial entities to this market will depend on the available business models and the level of risk in the investment infrastructure. The issues may vary in different sectors and industries. In the following we discuss these issues where possible but they will require more detailed analysis in some cases.

## 6.1 Soils

### 6.1.1 **Introduction**

## Case Study: High-tech grapes

Maria's vineyard produces premium fruit contracted to a major winery whose processing infrastructure allows both small (2t) and large (150t) ferments. It's current, and well established, market opportunity is for a premium Shiraz table wine that sells for $20/bottle. However, it also produces an 'ultra-premium' level wine which retails at current release for $120/bottle and in cool years favourable to the synthesis of rotundone, an iconic peppery Shiraz may also be produced; the last time this wine was produced, it sold for $300/bottle.

Maria knows that most of her production either meets the 'C' grade fruit required for the $20/bottle product, although she is concerned that some parts of her vineyard can produce 'D' or even 'E' grade fruit if she is not careful to manage vine vigour and disease risk. Thus, in most of her blocks, irrigation management is critical, and, along with vine trimming on an 'as needs' basis, she can manage both yield and quality in most seasons' to ensure that her fruit meets the requirement for the $20/bottle product. To help with this, she has installed a network of soil moisture and climate (temp. humidity) sensors, uses the newly available variable rate irrigation system, and she purchases airborne remote sensing at veraison annually. However, further to advances in sensing technology, in addition to giving her valuable information about canopy vigour which she has accessed for years, she now also receives a prediction of the likely incidence and severity of several fruit diseases, derived from the hyperspectral sensing of chemical signals in the leaves, and predictions of canopy humidity derived from the various soil and climate sensors, along with her elevation model of the property.

Importantly, Maria knows that in two of her blocks, small areas consistently meet the A-grade requirements for the $120/bottle wine and she uses the hyperspectral sensing to check the status of these as input to her selective harvesting plan.

This year has been cool. Using her DEM and high res. soil survey, and a cloud-based data analysis service which takes a feed from all of her spatial data sources, Maria has identified another area in one of her blocks which, due to the interaction between topography (orientation from north), soil mineralogy and microbial population, she is confident will yield fruit that is high in rotundone. She generates a selective harvesting plan map from her data analytics, and, using her weather sensors and a locally-calibrated phenological model, arranges a tasting schedule for the winemaker in the few days prior to expected harvest, to ensure that the selective harvest is optimised to maximise her fruit quality opportunity.

In such a way, Maria receives the best prices for her fruit, yields no 'D' or 'E' grade fruit and also gets paid a premium for enabling the winemaker to maximise the production of both the premium and ultra premium wines, and the opportunity to market an icon wine from this vintage. As a consequence, she is able to invest in a new Lidar system to estimate both canopy volume and potential pruning weight so as to direct the robotic pruning of her vines such that bud numbers retained for next season are optimised to the winery production portfolio.

**Box 2: A case study about grapes, sensor technology, and cloud-based analytics**

The soil is one of the primary focus areas for farming decisions. Knowledge of key soil characteristics is a foundation for achieving sustained production and productive capacity. However, without an adequate information base, the distribution and characteristics of soils as they impinge on farming-system decisions are neither obvious nor easy to monitor. As a consequence, better farming-system decisions require a diagnostic system both to identify the most appropriate settings for management and to monitor how the soil (and the soil–plant system) are functioning.

Three important components of the diagnostic system are:

- an understanding of how soils vary across the paddock, farm and in the context of the broader landscape (e.g. maps of soil properties and functional types)
- an ability to detect and interpret soils change with time (e.g. availability of nutrients, pH, organic carbon, plant-available water)
- a capacity to forecast the likely state of soils and impacts on the production system under the available land management options and experienced weather and climates (e.g. through the use of simulation models).

In addition, increasingly farm management needs to manage environmental impact (through minimising environmental loads).

An effective soil-information system would provide the relevant information (function, scale, timeliness) to increase agricultural efficiency, reduce risk and raise productivity.

Current Australian soil-information systems fall well short of this ideal. This section provides an overview of the current Australian soil-information system and its evolution. It suggests improvements to that system to:

- optimise the use of the information currently available
- build new systems that bridge the gap to what is needed
- create new alliances around improved soil information
- harness new data streams as part of a digital agricultural system.

Soil data and information concepts: In much of this document, we have distinguished between data and the information derived from data after analytics have been applied. The distinction is more difficult with soil. While there are data elements (e.g. a measure of soil pH at a certain depth), a more complex mix of soil data (information) is usually what is available and is accessed (e.g. soil type, plant-available water capacity). It has required significant analytical steps to produce and is usually styled as the components in a soil-information system. In this section, we will for the most part thus refer to 'soil information'. With changes in how soil data are captured, this dependence on analytics is changing and increasingly soil data elements are sensed or estimated and then used directly in modelling and analytics. The soil-information legacy, however, is for the most part data packaged into useful soil information.

We envisage two complementary solutions. The first is the creation of the Australian Soil Information Facility (ASIF). This concept has been developed by the Australian Soil Network[4] and involves a systematic harnessing of the existing public soil-information repositories around the country to provide simple and direct access to the best and most relevant soil information everywhere. ASIF will connect with private data where possible and mutually beneficial. The second solution uses advances in data analytics and information technology to provide soil-relevant data[5] from the information collected on-farm and across farm communities.

---

[4] The Australian Soil Network is responsible for implementation of the National Soil Research, Development and Extension Strategy. It also provides oversight for the National Committee on Soil and Terrain which includes representatives from each public-sector agency with an interest in soil information.

[5] Soil-relevant data implies the collection of data streams that, while not directly measuring soil attributes, with appropriate analytics provide soil-relevant information. Examples include soil moisture dynamics, nutrient status, biomass and yield variation and emergence patterns.

### Value to agriculture and agricultural decisions

The first *State of the World's Soil Resources Report* by the Intergovernmental Technical Panel on Soils (ITPS 2015a) concluded that 'human pressures on soil resources are reaching critical limits. Further loss of productive soils will amplify food-price volatility and potentially send millions of people into poverty'. Within Australia, soil acidification, unsustainable rates of soil erosion, loss of soil organic carbon and nutrient imbalances (deficiencies and excesses) are recognised as significant threats to soil function and remain difficult to ameliorate (ITPS 2015b; McKenzie et al. 2017). If left unchecked, these problems will constrain Australia's ability to build productivity and take advantage of agricultural opportunities created by a growing population and demand for exports. A concerted effort to further improve soil management is required and this needs to not only include better diagnostic systems for determining when and where soil function is being compromised but also effective systems for developing and implementing farm management practices that restore or enhance soil function.

Achieving these changes requires the capacity at farm level to make decisions informed by knowledge of the soil state, the levels of key soil attributes and the interaction between land management choices and the soil.

Unlike the US and some European countries (where farm-scale soil maps have been produced), Australia has not had a long-term and detailed soil survey program. As a result, Australian farmers do not have access to comparable farm-scale soil information, although broad-scale and consistent mapping is available in some jurisdictions (e.g. Western Australia, South Australia and Tasmania).

In addition, access to these institutional soil-information systems is developing slowly or deteriorating and is out of step with the rapid development of on-farm requirements for soil information. Institutional soil information reform is needed and is the focus of the ASIF proposal.

Soil information (and streams of soil data) is now available from other sources, including from farms, private sector actors, agribusiness and, with data fusion approaches, can be inferred from proximal and remote sensing. This represents a complementary route to useful soil information at the farm and decision scale. This theme is further developed below.

## 6.1.2 **Current state**

The evolution of institutions for managing soil resources (and soil-information systems) parallels the history of land use in Australia. The initial European impact on soils in most parts of Australia was profound and in some areas catastrophic. Severe soil degradation, particularly in the 100 years after 1850, resulted in declining crop yields and the dust bowl years of the 1930s and 1940s (Bolton 1981; McTainsh and Boughton 1993; McKenzie et al. 2004; Angus 2001). The large economic, social and environmental costs led to a range of institutional responses that have shaped how public soil information is obtained and managed to this day.

While the responsibility for soil and land management – and therefore the information needed to support that management – has traditionally been a state and territory responsibility, coordination arrangements were established post 1936 and reached a peak with the relatively significant investments in Landcare and related programs through to the early years of the 21st century. While the strength of the Landcare movement lay in community groups and networks, unprecedented Commonwealth investments into natural resource management and soil-information development were associated. As a result, significant improvements in soil and land management have occurred during the last 25 years (e.g. SOE 2011; ITPS 2015b). However, in recent years, the scale of investment into general natural resource management programs has declined. Importantly, for soil-information development and availability, this has resulted in the decline of the national coordination programs that had connected the various agency soil-information systems.

Table 2 provides a summary of public-sector soil survey and monitoring programs relevant to agriculture. It highlights that active field programs of soil survey and monitoring have ceased in several jurisdictions and that most data collection occurred during the 1990s and 2000s. A cursory review of the links to online soil information will also reveal how difficult it is to obtain an overview of soil-related issues across jurisdictional boundaries. This is a significant information barrier for those investing in particular agricultural industries (e.g. establishing research and development priorities, identifying opportunities for industry expansion, providing coordinated and coherent extension services). McKenzie et al. (2017) document some of the resulting risks and consequences in relation to soil acidification where most jurisdictions have out-of-date information. They conclude that the extent and severity of soil acidification appears to be more serious than indicated by even the most recent continental datasets provided by the Soil and Landscape Grid of Australia (SLGA) (Grundy et al. 2015). The SLGA is a major advance in the provision of fine-resolution gridded soil data but the source data on which it relies were mostly collected one or two decades ago.

**Table 2: Summary of public-sector soil survey and monitoring in Australia**

| JURISDICTION | SURVEY COVERAGE AGRICULTURAL LANDS | MONITORING CAPABILITY | PROGRAM STATUS | ONLINE ACCESS |
|---|---|---|---|---|
| **South Australia** | Consistent land resource surveys at scales of 1:100K and 1:50K | Monitoring of some key drivers of soil change (e.g. surface cover) – no formal network | Comprehensive surveys undertaken in the 1990s and 2000s. Field programs effectively ceased | Department of Environment, Water and Natural Resources |
| **Western Australia** | Consistent land resource surveys mostly at 1:100K | Monitoring of some key drivers of soil change (e.g. surface cover) – no formal network | Comprehensive surveys undertaken in the 1990s and 2000s. Field programs effectively ceased | Department of Primary Industries and Regional Development |
| **Tasmania** | Mix of soil and land resource surveys with an up-to-date digital coverage | Formal network of monitoring sites and reasonable understanding of recent and current soil change | Most surveys undertaken in the 1990s and 2000s with recent field programs and digital soil mapping. Limited ongoing resources for monitoring | Department of Primary Industries, Parks, Water and Environment |
| **Northern Territory** | Extensive land resource surveys to support pastoralism with more detailed soil and land resource surveys in areas where agriculture is intensifying | Networks of rangeland monitoring sites with limited direct soil monitoring | Long-standing survey program and field capability. Current surveys are focusing on areas with potential for agricultural intensification | Department of Environment and Natural Resources |

| | | | | |
|---|---|---|---|---|
| **Queensland** | Diverse soil and land resource survey coverage with the level of detail being proportional to the intensity of land use | Monitoring sites are being established as funds permit | Peak of survey activity in the 1990s and 2000s building on a strong history of activity. Field programs are limited at present | Queensland Government |
| **Victoria** | Diverse soil and land resource survey coverage with a range of interpreted products available at the district and state level | Limited number of monitoring sites | Significant field activity during the 1990s and 2000s and a strong focus on capturing legacy data. Limited field activity at present | Victorian Resources Online |
| **New South Wales** | Diverse soil and land resource survey coverage with a range of interpreted products available at the district and state level. No recent mapping at scales of 1:100K or better for some key agricultural areas | Monitoring sites established across a range of agricultural districts | Peak of survey activity in the 1990s aimed to upgrade the 1:100K survey coverage but it remains incomplete. Most focus in the 2000s on monitoring and capturing legacy data. Field programs are limited at present | New South Wales Office of Environment and Heritage |
| **Australian Government** | Custodian of legacy surveys (e.g. CSIRO land systems) and national compilations (e.g. ASRIS, SLGA) | No formal programs of soil monitoring although national R&D programs have provided insights into soil change (e.g. SCaRP (Baldock et al. 2013)) | Significant soil R&D capability in CSIRO but declining support for national coordination of soil information activities | Australian Soil Resource Information System and the Soil and Landscape Grid of Australia |

Thus, significant institutional constraints remain. Most soil-information gathering activities are currently funded through short-term government programs, private companies (e.g. fertiliser companies), individuals, or in response to specific regulatory requirements (e.g. environmental impact statements). These have not produced the enduring, accessible and broadly applicable information systems that are needed to meet the requirements of nearly all stakeholders – and which are available in comparable countries such as the US.

Despite these significant challenges, the Australian soil-information system is internationally recognised for being innovative, collaborative and responsive to contemporary issues. This is largely due to the enduring and effective partnerships between operational agencies and research groups that have been responsible for a range of innovations including digital soil mapping, proximal sensing and web-based delivery of information services (McBratney et al. 2003; Arrouays et al. 2014, Hicks et al. 2015; Grundy et al. 2015) within a collaboration model that allowed joint efforts in standards, approaches and system improvement.

### The collaborative model and access to public soil information

In the 1990s, the Australian Collaborative Land Evaluation Program (ACLEP) was established to develop a coordinated approach to land resource assessment across Australia. The program included all commonwealth, state and territory agencies involved with land resource assessment. ACLEP was jointly funded by the Australian Government (initially through its National Landcare Program) and CSIRO. In many ways, the model was a continuation of the original institutional arrangements established in 1936.

ACLEP promoted better procedures for acquiring and using soil and land resource information in government and private industry. This was achieved by setting national standards for soil and land resource assessment, providing a forum for communication between technical specialists, attempting to develop a network of soil and land reference sites across Australia and encouraging research into methods for land resource assessment. ACLEP received strategic direction from the National Committee on Soil and Terrain (NCST) and for most of its existence had a formal line of reporting through to the relevant Ministerial Council of the day.[6] ACLEP was active from 1990–2015 but is currently unfunded. It concentrated on:

1. Supporting the partner agencies through capacity building, development and publication of standards, and testing of new survey methods
2. Communication of soil and land resource information to a broad range of users
3. Development of new methods of digital soil mapping
4. Construction and delivery of the national Australian Soil Resource Information System: one of the world's first online national soil-information systems
5. Development of new standards for soil data systems and web-based services
6. A major upgrade of the National Soil Archive
7. Development of the Soil and Landscape Grid of Australia: the first continental-scale implementation of the *GlobalSoilMap* Technical Specifications (Arrouays et al. 2014).

As a result:

- users of soil information now have unprecedented access to harmonised soil data and information collected over more than 50 years
- major technical advances and major new products have been delivered because of the network and collaborative arrangements fostered by ACLEP
- ACLEP provided a pathway-to-impact for research teams in universities (e.g. The University of Sydney) and CSIRO.

Despite these achievements, the collaborative model forged by ACLEP is no longer viable because of inadequate funding and the lack of a formal institutional mandate.

### 6.1.3 **Emerging trends, changes and drivers**

Understanding and managing soil change across Australia has been recognised as a priority by the Australian Government (e.g. in its Science and Research Priority on Soil and Water). It is central to the Soil RD&E Strategy (e.g. Priority Three) and important to a wide range of industries, governments and communities. A recurring issue has been provision of the enabling infrastructure for collecting, curating and analysing soil information. The need for new

[6] Initially the Australian Soil Conservation Council, then the Natural Resources Ministerial Council and more recently the Primary Industries Ministerial Council until its disbanding in 2013. It now reports indirectly to the Standing Council on Primary Industries (SCoPI) but the scope of the NCST extends well beyond agriculture.

arrangements to achieve more open access to information has been recognised in a range of reviews and reports (e.g. Campbell 2008; NCST 2013; McKenzie 2014; ITPS 2015a; Keogh and Henry 2016). In addition, it is now clear that the digital revolution has created exciting new possibilities that overcome past obstacles.

In Australia, several domains have made great strides in developing new and integrated national observing systems and forecasting capabilities *without* having to establish new agencies (e.g. Integrated Marine Observing System (IMOS), Atlas of Living Australia (ALA)). Common to each of these activities is some form of national facility – hosted by an existing institution – that provides the necessary infrastructure for information management and computing. These facilities are notable for their clear strategic outlook, effective collaborative arrangements, and technical excellence.

Based on this model, NCST (2013) and the Australian Soil Network (ASN) proposed a new soil-information system for Australia that supports the best features of the current system, takes advantage of new technologies and avoids the restrictions in the ACLEP model. Central to these proposals are the establishment of the Australian National Soil Information Facility (ASIF). This directly addresses Priority Three of the national Soil RD&E Strategy and it also responds to the recommendations made by Keogh and Henry (2016) in their analysis of global developments in digital agriculture and the steps that Australia needs to take to ensure benefits are quickly realised (e.g. Recommendations 3, 5, 7 and 9). ASIF is possible because of some disruptive trends in soil data collection and information derivation. These include:

- the sensor revolution:
    - miniaturisation and field deployment of analytical instruments that were once solely for laboratory use (e.g. gamma-ray detectors, infrared spectroscopy and X-ray fluorescence) – these can replace current qualitative methods for characterising soils in field surveys
    - dramatic increases in the spectral, spatial and temporal resolution of airborne and satellite-based sensors that are producing images and datasets of widespread value (e.g. high-resolution digital elevation models, sensing of elemental composition and soil water content, actual evapotranspiration)
    - revolutionary new measurement techniques in molecular biology that promise new opportunities for plant breeding (e.g. large-scale phenotyping) and understanding of ecosystem function and condition
    - rapid advances in communication technologies that enable the development of inexpensive sensor networks that are web-enabled.
- advances in computing power and simulation modelling leading to more numerically intensive models, higher resolution spatial and temporal inputs and outputs and therefore realistic representations of biophysical systems
- formalisation of methods (often called model-data assimilation) for analysing multiple lines of evidence that can place bounds on the likely state of a system thereby reducing uncertainty in estimation and prediction – this is now being applied to soil mapping and estimations of stores and fluxes in soil (e.g. of water, carbon, nutrients, solutes). With

time-series of remote sensing, this allows forecasting, now-casting and hindcasting of agricultural systems

- development of effective approaches to soil-information interoperability (e.g. ANZSoilML), web services (e.g. ASRIS, Figure 1) and related technologies with the potential to connect and access disparate and separately managed soil-information systems.

We consider the development of ASIF an important part of the strategy for developing this capacity in Australian digital agriculture.

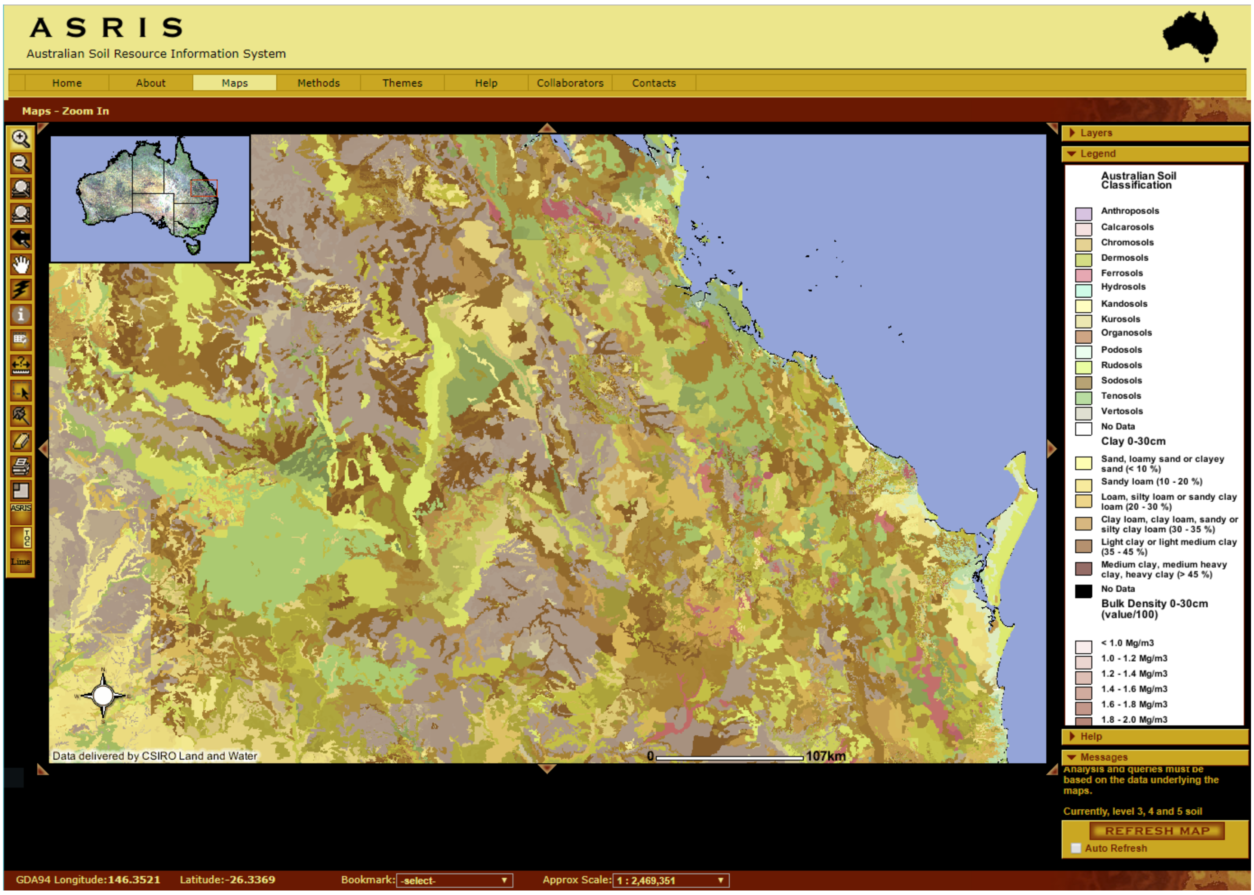



**Figure 1: ASRIS web interface showing user-defined base map**

## 6.1.4 Opportunities, roles and responsibilities of the public and private sectors

Australia's public-sector soil-information agencies collect soil information for internal policy drivers but maintain and supply public soil-information systems for a number of 'public good' areas. These include: reducing transaction costs and information failure, identifying and responding to externalities, support of regulatory and reporting responsibilities, and enabling research and development.

Effective government policies and investments can overcome many of the issues outlined above and the establishment of the ASIF forms part of the strategy. Effective engagement with the private sector can improve the efficiency of data collection in the following ways:

- capture of data associated with the several hundred thousand soil tests that are undertaken annually by commercial soil-testing services provides a mechanism for monitoring soil change (e.g. Arrouays et al. 2012; Rawlins et al. 2017)
- capture of data collected for environmental impact assessment and planning approvals
- stimulate the development of soil-information service providers in the private sector that can contribute to ASIF.

Collection and use of soil information by private actors in agriculture has been an important part of business practice associated with the provision of services and advice, supply of inputs and in various forms of planning, reporting and assessment. These data have tended to be held as key intellectual property or to protect privacy and commercial interests. With appropriate policy and technical settings, it is envisaged that these rich data sources can be part of ASIF and therefore broaden the scope and timeliness of the public integrated system.

Changes in the structure of private actors in the agricultural advisory system, increased soil-information capacity in agribusiness and increased capacity on-farm to collect and monitor soil status is now providing new opportunities in soil-information supply and demand in the private sector. In addition, the new web services provided by ASIF as envisaged here can also form the basis for new businesses in the knowledge economy or provide the context for new soil-information services. For example, there is potential for locally based soil data marketplaces; especially if the data streams available from farm machinery, soil sensors and appropriately interpreted proximal and remote sensing are included. Here we envisage local and intense soil information available on-farm or across farm communities being used in context with ASIF.

### 6.1.5 **What needs to be done to get there**

The task of establishing the ASIF would involve:

- Engage the key partners and agree on roles and responsibilities

  Convene leaders of the key partner agencies and gain agreement on their respective roles and responsibilities. Some of these key agencies include: lead state and territory agencies, the Australian Government, rural research and development corporations, CSIRO, The University of Sydney, Geoscience Australia, and the new CRC for High Performance Soils

  Require a formal legal agreement. The nature of this agreement, at its simplest, could be a register of agreed data services and products that will be provided by member organisations through data interoperability and open data standards. New mechanisms for establishing this formal mandate are also starting to appear. The draft reforms on data availability and use proposed by the Productivity Commission provide good solutions to several of these institutional issues, particularly those relating to the National Data Custodian, Accredited Release Authorities and the declaration of National Interest Datasets. While these proposals are at an early stage of development, they appear to provide the necessary institutional framework for ASIF.
- Establish links with other facilities and key networks such as the Terrestrial Ecosystems Research Network (TERN) and the Australian National Data Service (ANDS). Relevant

operational agencies include Geoscience Australia, the Bureau of Meteorology (BoM) and the Australian Bureau of Statistics (ABS).

The success of ASIF also depends on effective engagement with three collaborative networks:

1. The Australian Soil Network and more specifically, the National Committee on Soil and Terrain
2. The Australasian Soil and Plant Analysis Council (ASPAC): this network provides access to private-sector soil-testing companies and associated data sources
3. The International Network of Soil Information Institutions which has been established by the Global Soil Partnership (GSP) and is responsible for delivering the global soil-information system. Australia has been a significant contributor to the GSP and engagement via ASIF will bring a range of benefits and, in particular, enable integration with activities in the Asia-Pacific region.

- Secure long-term funding

  A new investment of approximately $5M per annum is required to establish ASIF. This would complement existing investments by existing agencies (e.g. state and territory governments, CSIRO, Australian Government Department of Agriculture and Water Resources). This funding base needs to be broadened and made more secure.

- Confirm priorities for provision of soil information (at the decision scale). These would include:

  *Soil nutrients*: Nutrient imbalances are widespread in Australian agriculture. The focus would be to integrate existing land resource surveys, the Soil and Landscape Grid of Australia, and several large data compilations by individual projects (e.g. Better Fertiliser Decision project, National Land and Water Resources Audit) with the large quantities of soil test data collected by farmers, agribusinesses and the fertiliser industry (most of which is currently inaccessible).

  *Acidification*: Soil acidification is a widespread and serious problem that has the potential to cause irreversible damage to soils, particularly across southern Australia, in select tropical landscapes, and in areas where product removal and leaching are contributing factors. Data source improvements are needed to ensure estimates are up-to-date and to enable more accurate estimation of the Net Acid Addition Rates of different farming systems. Again, integrating public and private data sources and maximising data accessibility are essential.

  *Carbon*: Understanding trends in soil carbon stocks (and therefore soil organic matter) is essential for achieving efficient and sustainable soil management. It is increasingly required for accreditation and monitoring for a range of purposes including market access, official statistical reporting (e.g. Sustainable Development Goal 15.3), carbon trading and other emerging international schemes (e.g. the 4-per-1000 initiative).

  Data services on soil carbon need to include a regular update of the Soil and Landscape Grid of Australia and mechanisms for integrating local farm measurements with broader-scale measurements across the landscape.

*Soil-water balance*: Real-time measurement and estimation of the soil-water balance are the current focus of several major national projects. Advances in proximal sensing (e.g. Cosmos probes, sensor networks) and time-series remote sensing have improved the spatial and temporal resolution of data streams. The use of the resulting information is widespread and includes drought and flood forecasting, pasture management, crop-yield forecasting, fertiliser decisions and agricultural management more generally.

*Soil microbial populations*: Major advances in molecular biology and activities such as the BASE project are providing completely new insights and potentially the basis for new interventions relevant to carbon and nutrient management in agricultural systems. The soil biological component of the ALA and activities such as the BASE project are both a source and user of new soil data services. A major opportunity for ASIF is to ensure data services and the supporting computing infrastructure are closely aligned with existing systems for biodiversity. This will generate economies of scale and accelerate the rate of discovery and innovation in the management of soil biology cross the Australian landscape.

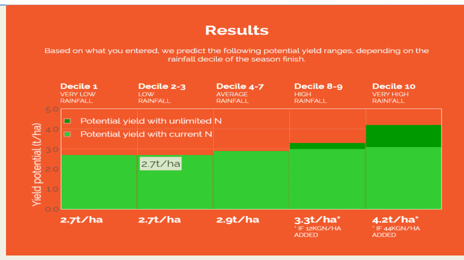
Finally, reinvestment into a strategic program of technically advanced soil survey and monitoring is essential. Future soil-information needs will not be satisfied by relying solely on the analysis of large aggregations of soil data collected for a wide range of disparate purposes (e.g. soil nutrient testing, environmental impact assessment, monitoring). It also requires carefully designed field survey and monitoring programs that are based on a scientific understanding of how soils vary in the field. Investment into this knowledge base will also ensure that Australian agriculture maintains access to specialists who understand the role of soils in agricultural production across the continent's diverse landscapes.

## 6.2 Weather and climate

### 6.2.1 **Introduction**

Australia's farmers have managed extreme fluctuations in weather and climate throughout Australia's farming history. A frost can wipe out a wheat crop in one morning. A 5-year drought can be the ruin of a grazing property in outback Queensland. Australia's climate is one of the most variable in the world and can be traced as a major influence on our interannual food productivity. The best way to adapt to such a system is to be able to forecast it from the next 10 minutes to the next decade, and translate this to optimal decision making in the face of inherent uncertainty.

## Case Study: An app for predicting yield from rainfall




**Yield Prophet Lite** is a free tool that lets you estimate potential yield values for your crop given different rainfall amounts and fertiliser application rates. It also gives the rainfall likelihood for the remainder of the growing season. Currently Yield Prophet Lite models four cereal crops, wheat, barley, canola and oats. The tool requires weather, soil water availability, soil nitrogen and carbon levels to estimate the likelihood of achieving yield level categories. The tool is built on the reputable crop simulation model APSIM and the results are generated in terms of yield potential and the likelihood of potential yield with and without additional nitrogen.

Weather forecast information is sourced from the BoM POAMA/ACCESS forecasting models while soil information requires farmer values with soil carbon levels also available from the CSIRO Soil and Landscape Grid databases.

Improved weather and soils data that is readily available will lead to greater leverage of the underlying research base with resulting improvements to profitability. It will provide an information foundation for growers and advisors to forecast yield, manage climate and soil water risk, make informed decisions about nitrogen and irrigation applications, match inputs with the yield potential of their crop, assess the effect of changed sowing dates or varieties and assess the possible effects of climate change. Integrated services such as soil sampling and testing services, apps to enter farm data, data repository services and technologies to allow weather station connectivity will develop from these data investments.

**Box 3: A case study on Yield Prophet Lite, an app for predicting yields given rainfall amounts and fertiliser application**

Weather is considered to be variation that occurs day-to-day or hour-to-hour. Climate describes the longer-term patterns of weather. This can range from monthly time scales, such as describing the hotter-than-average temperature for July, or multi-decadal time scales, such as describing the long-term trend in decreasing rainfall in the next 50 years.

As the time scale of the forecast increases, so does the uncertainty. Weather forecast models are more deterministic (single value) than probabilistic (range of possible outcomes), as compared to climate models that are more probabilistic than deterministic. As such the information obtained from each is often used in different ways.

Climate forecasts are typically categorised by time scales which are sub-seasonal (1 week to 3 months), seasonal (the next 12 months), multi-year to decadal (next year to next decade) and climate change (long-term changes from 30 to 100 years).

### 6.2.2 Current state of datasets

Historical and future weather and climate forecasts come in a range of different shapes and sizes from a range of sources (Table 3).

While the underpinning physics of weather and climate models is the same at each time scale, the structure of the spatial grids and time steps alters. We can expect as computing power increases into the future the grid size and time step will decrease, bringing greater resolution to forecasts.

At the weather time scale, forecast grids are often of the order of 12–25 km with 70 vertical levels into the atmosphere and a time step of 6 hours. These models generate forecasts out to 10 days.

Climate models need to be run for longer periods and so must make sacrifices in resolution and time step to account for the larger computational cost. These generally extend out to 6 months at daily 60–100 km resolution.

Climate change models run for the next 100 years and have spatial resolutions of around 100 km.

**Table 3: Sources of climate and weather data, and their typical resolutions**

| MODEL OR DATA | SPATIAL RESOLUTION | TEMPORAL RESOLUTION |
|---|---|---|
| **Historical observations** | | |
| **SILO** | 5 km grid or stations | Daily |
| **AWAP (BoM)** | 5 km | Daily, monthly |
| **Weather – next 7 days** | | |
| **ACCESS-C (BoM, capital cities and surrounds)** | 4 km | Hourly |
| **ACCESS-TC (BoM)** | 12 km | Hourly |
| **ACCESS-R (BoM)** | 12 km | Hourly and 3-hourly |
| **ACCESS-G (BoM)** | 25 km | 3-hourly and 6-hourly |
| **ADFD (Multi-model forecaster edited consensus product)** | 6 km (3 km for Vic/TAS) | Hourly, 3-hourly and daily |
| **Sub-seasonal to seasonal (next month to 12 months)** | | |
| **POAMA (BoM, to be decommissioned in 2018)** | 250 km | Daily |
| **ACCESS-S (BoM, available 2018)** | 60 km | Daily |
| **Downscaled and calibrated version** | 5 km | |
| **Multi-year to decadal (next year to next 10 years)** | | |
| **CAFÉ (CSIRO)** | 250 km | Daily |
| **Climate change (out to next century)** | | |
| **CMIP5** | typically ~100km | |

Underpinning the weather and climate models is a need for accurate and comprehensive observations to initialise the models and calibrate the output. Having the most accurate possible picture of the current state of the atmosphere, oceans and land is crucial for initialising models. For example, climate variability is particularly driven by changes in temperature and currents at the surface and subsurface in the ocean. Critical pieces of observational infrastructure include (but are not limited to) the Argo international temperature/salinity profiling floats; ACORN-SAT long-term Australian temperature record; high temporal and high spatial resolution satellites; radar; and shared access to third-party automatic weather/water/soil networks. The maintenance and expansion of such networks ensure the ongoing success of Australia's weather and climate mitigation strategies.

## Historical weather data

Historical weather data is an extremely valuable commodity for understanding our local environments and improving weather forecast skill. Traditionally, farmers collect on-farm historical weather information to:

- better understand the operating environment
- critique the effectiveness of their management practices
- help predict how certain crops/pastures would perform in certain seasons
- understand the potential production in a season.

Over time, there have been no fundamental changes in the types of weather data being collected; however, the measurement devices themselves have advanced. For example, traditional weather measuring devices included a Stevenson-screen with a max/min temperature, wet bulb, rain gauge, wind vane, evaporative pan, and a device to measure sunlight hours (a glass ball with a strip of paper on a mechanism). Now, weather-measuring sensors collect data automatically using electronic tipping bucket rain gauges, short-wave and long-wave radiation sensors, and ultrasonic wind sensors.

The official and co-operative weather observation networks of the BoM provide a wide range of real-time data feeds from across Australia. At a glance, the network contains over 2600 rain gauges, 63 radars, ~685 automatic weather stations, 775 river height gauges, ~200 evaporation pans, 863 anemometers (wind), 183 ceilometers (clouds), 7 satellite observing stations, 50 soil temperature probes and >200 co-operative sites. All of these and more are managed by eight manned observation hubs located in every state, contributing to more than 1 billion observations processed by the BoM forecast models every day. The spatial distribution is also broadly focused on cities and agricultural zones. For example, 69% (81%) of the time you are anywhere in Australia, you will be within 50 km (75 km) of a rain gauge connected to the BoM network.

Beyond the official BoM network of weather stations there are many private weather stations and networks collecting data. These are primarily installed to assess conditions at the paddock scale or where complex topography also comes into play – for example, a paddock on one side of a mountain will have very different weather to what is recorded on the other side. Techniques are now being developed to add these third-party networks to the BoM suite to both improve the national modelled observations and to take existing weather forecasts and records and calibrate them to the paddock of interest where sufficient weather records are available.

Gridded products of historical weather have been developed to help us study changes over Australia. To obtain a grid of historical weather information, point observations are used and then varying techniques such as interpolations or dynamic models can be used to 'fill in the gaps'. SILO and AWAP are examples of these products available for Australia (Table 3).

### Weather forecasts

Weather forecasts, considered to be skilful out to at least 7 days, are valuable for tactical decisions. Significant advances in skill were made with the introduction of satellite data and supercomputers with notable jumps in the mid-1980s and late 1990s (Figure 2). Weather forecasts along with derived products such as evapotranspiration are now available quickly and simply in apps for use in making on-farm decisions.

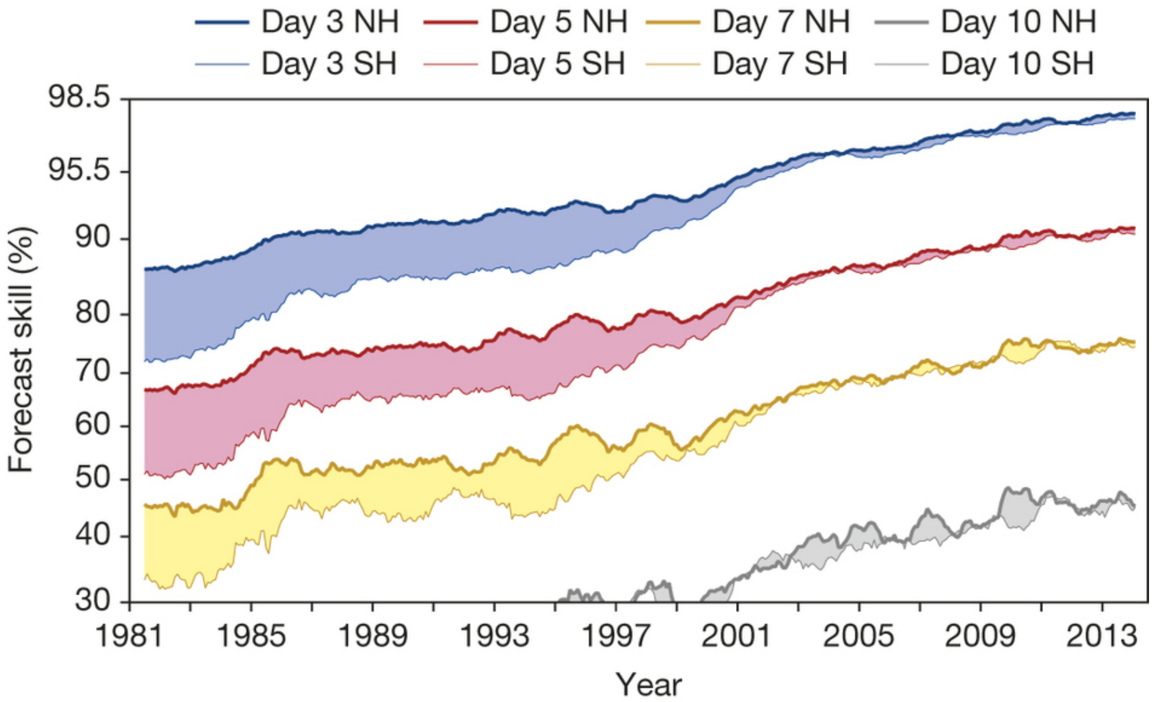



**Figure 2: Increasing skill in weather forecasts over time for various outlook time periods in the southern (SH) and northern (NH) hemispheres**

From Simmons and Hollingsworth (2006)

In Australia, operational weather forecasting is provided by the BoM which also enables third parties to develop and maintain forecast services. ACCESS-R and ACCESS-G are the regional and global deterministic numerical forecast models, respectively, currently operated by BoM. They run four times (ACCESS-R) and twice (ACCESS-G) daily and provide forecast data out to 72 and 240 hours, respectively, with a horizontal resolution of approximately 12 and 25 km, respectively (Table 3). The models are based on the UK Met Office Unified Model and published on the BoM website. Forecasts for major cities and some regional centres are published using the ACCESS-C model, capable of forecasting out to 36 hours at 4 km resolution and run four times daily.

The BoM combines each of these models with the major international deterministic forecasting models, weighted according to recent and historical performance, to create a consensus forecast twice per day. The forecasters in each state office then vet the consensus forecast grid against the initial model guidance, before manually editing the consensus to include known local variations. This final forecast grid is known as the Australian Digital Forecast Database (ADFD), and is used to generate the official forecasts seen all throughout Australia. This consensus approach is internationally recognised as best process and ensures model biases are reduced in real-time.

Figure 3 shows the progression of technology used for weather forecasting. Hand-drawn synoptic charts have been updated with computer-generated systems and high-resolution satellite pictures. Detailed forecast information can now be readily obtained, tailored to specific and remote locations and viewed from a mobile phone.

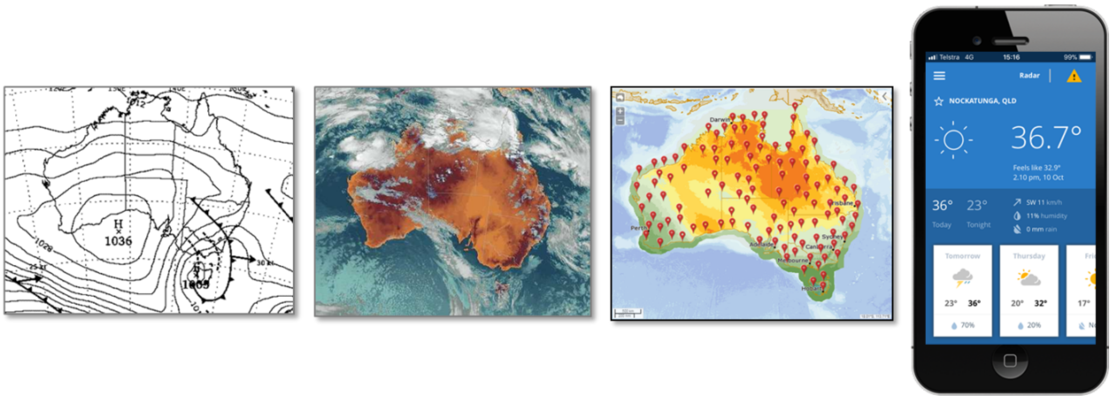



**Figure 3: The progression of weather forecasting technology**

## Climate forecasts

**Sub-seasonal to seasonal**

Forecasts at the sub-seasonal scale (10 days to 3 months) have become a recent focus of meteorological research driven by the knowledge that on-farm decisions would be enhanced with skilful forecasts at such a time scale. Examples of such decisions that could be informed by a sub-seasonal forecast include knowing the chance of sufficiently dry conditions to allow for muster, or knowing the likely total rainfall forecast over the next 2 weeks to estimate the impact of adding nitrogen to a sugarcane crop and the consequences of runoff into waterways.

The challenge is that weather models tend to have skill at the daily time scale only up to 10 days, beyond which time chaotic factors begin to come into play. Sub-seasonal forecasts must aggregate to longer probabilistic time scales (e.g. the likelihood of receiving more than 25 mm in January) or harness synoptic features that can persist beyond this threshold, such as the Madden Julian Oscillation in the tropics.

At the seasonal scale (3 months to a year), decisions can be made around factors such as which crop to plant, nitrogen applications and stocking rates. At this time scale probabilistic predictions are a must though the skill of these predictions varies according to location, variable of interest and time of year. For example, predicting winter and spring rainfall in April is quite difficult due to a well-known 'predictability barrier' associated with the uncertainty of the El Niño Southern Oscillation. However, later in the year this uncertainty is reduced and predictions become more reliable.

Agricultural forecasting is traditionally based on statistical climatology as opposed to dynamical climate model forecasts. Statistical climatology approaches are where past climate records are used to represent the full range of possible climates that the upcoming year might bring. This range could be narrowed by considering particular likely phases of the Southern Oscillation Index and the El Niño–Southern Oscillation (ENSO).

The increase in the skill of dynamical models has meant that they are now becoming more useful than their statistical counterparts for predicting sub-seasonal and season-ahead climate. The outputs are also more applicable to an end user, in that a climate model incorporates all the climate factors (ENSO, Indian Ocean, Subtropical Ridge, MJO, SAM, etc.) that may affect the climate of a particular region, reducing the requirement for farmers to interpret often confusing indices. Furthermore, as climate change progresses, the past climate is not necessarily a good indicator of the future, meaning the skill of statistical models will decrease into the future.

## Case Study: how a "button" can be used to measure frost

Researchers are taking a landscape view for collecting information on the presence of frost. They have been using the Thermochron iButton to track how cold air pools in the landscape and develop better forecasting tools. This gives us the ability to see which properties are more prone to frost than others under different synoptic events.

Built in the USA and cheap, iButtons were originally designed for the transport industry to track temperature and/or humidity spikes when goods were being transported. With their small size and in-built computer chip, iButtons are a way of increasing the density of data collected without being cost prohibitive. The sensors are wrapped in plastic shrinkwrap to waterproof them and placed on poles well above potential damage from rodents and other animals.

A digital elevation map was used to space the sensors at different elevations and along these contours. The data is currently retrieved from the iButton sensors using a specialised handheld scanning device. Given the high labour cost of this method of retrieving the data, a wireless network is being developed based on a DigiMesh platform which allows each node in the network to act as router and can repeatedly relay data though the network of nodes until the message arrives at its destination.

Industry stakeholders have been excited by this technology and its potential for giving us a better understanding of production risk.

**Box 4: A case study on a novel way of measuring frost on a farm**

The Predictive Ocean Atmosphere Model for Australia (POAMA) of the BoM is a seasonal climate model that operates at a low-resolution (250 km) grid. Research has shown that using variables such as temperature, radiation and rainfall to feed crop models like Agricultural Production Systems sIMulator (APSIM) has resulted in useful grain production estimates across regional Australia.

The BoM is in the process of upgrading their current POAMA-2 system with a new seasonal-forecasting system referred to as ACCESS-S (the seasonal prediction version of ACCESS). ACCESS-S will operate at a higher resolution (60 km) than POAMA-2 (Table 3), and will incorporate the latest developments from local and overseas sources. Daily output from this model will be available for purchase in hindcast mode or as an operational real-time forecast.

Internationally the sub-seasonal to seasonal (S2S) climate forecast has gained growing attention. An international collaborative structure was set up ('Subseasonal-to-seasonal prediction project'[7]) coordinated out of Korea, as requested by the World Meteorological

[7] Subseasonal-to-seasonal prediction project. http://s2sprediction.net/

Society. Aligned with this project is a database of climate forecasts from climate models around the world. The goal of this database is to promote the uptake of the sub-seasonal to seasonal climate forecasts by operational centres and exploitation by the applications community. It provides a focus for climate scientists to strive for as well as a resource of information for exploring our ability to provide climate information into digital agriculture. Currently this data is freely available in hindcast and forecast mode but only in the form of monthly averages.

#### Multi-year to decadal

Beyond the seasonal time scale, multi-year to decadal forecasts provide information to help with longer-term strategic decisions. In farming enterprises knowing whether the 'next year' will be good or bad helps to determine which paddocks to leave fallow or whether risky infrastructure investments should be made (e.g. expanding a cropping program, buying in extra livestock or buying new properties). The decadal time scale is also valuable for these same decisions and includes information for farming enterprises with longer growth or maturation cycles such as trees or vines.

Recently, CSIRO has invested significantly in developing climate forecasts on the multi-year to decadal time scale with the development of the CAFÉ model (Table 3). This model uses novel techniques for initialisation to push the boundaries of predictability into the decadal time scale.

#### Climate change

Climate change forecast information – looking at the next 30 to 100 years – includes extra elements of uncertainty. We don't know which emissions scenario we will track over the coming decades and models must therefore provide answers to a range of possible outcomes. Extra complexity is added as ongoing research can sometimes be contradictory on how the major climate features such as El Niño might change (if at all) under these future scenarios. Nevertheless, there is certainty around factors such as increases in global temperature and sea level rise that are valuable for agricultural policy decision makers across a range of industries.

Runs of climate change models are accessible through international data portals or via Australian databases. The raw output is stored on NCI. A more user-friendly approach to viewing future climate scenarios for Australia can be found on the Climate Change in Australia website[8] or the consistent climate scenarios portal.

### Forecasts at the farm and paddock scale

Climate forecasts at any time scale are provided on a global grid where the value in that grid describes the average conditions throughout the grid box. The typical agricultural user is interested in only their location, not the averaged conditions. In the absence of farm or paddock-scale gridded products, some method of downscaling and calibration is therefore required. Many techniques have been trialled with various pros and cons. The optimal method may not be the same for each agricultural domain and application. Recently a quantile mapping approach was developed to translate POAMA output to align with the SILO patched point data

[8] https://www.climatechangeinaustralia.gov.au/en/

and made freely available to researchers.[9] This opened up many opportunities to incorporate climate models into agriculture (e.g. the app Yield Prophet Lite). Areas for improvement in this calibration method have been identified and assessments are now taking place on how to improve calibration methods to take forecasts down to farm and paddock scales (<5 km resolution grids or point information).

### 6.2.3 Current set of information products

#### Value-added weather and climate information

Access to now-casts and forecasts for weather and climate has grown rapidly from simple newspaper and TV sources. The BoM website is now the most popular government webpage in Australia. Value-add companies such as WeatherZone and WillyWeather provide websites and apps that deliver weather information in creative ways using BoM and other sources. These secondary companies also provide API feeds to other websites. For example, WeatherZone feeds customised weather data to websites and apps such as MyMLA (https://www.mla.com.au/about-mla/mymla/) and Elders (http://www.eldersweather.com.au/), with relevant details of heat-stress or cold-weather warnings for livestock. In these cases the end-user is contributing to the design of the app in bespoke ways for their industry with usability features such as being able to read the app in direct sunlight (e.g. The Yield App).

Despite growing technology, there is still a desire to 'see the scientist' giving the forecast, much like the relationship that was built up with the TV weather presenter in the 1980s and 1990s. This 'face of the weather' aspect has grown into regular online YouTube clips and the appearance of scientists on programs such as Sunrise, The Project and Lateline. Domain-specific clips such as 'The Fast Break' (https://www.youtube.com/channel/UClDCIIl7gRZhUs03opGqH1g) are emerging as growers connect to characters such as Dale Grey.

#### Climate integration into decision-support tools

For farmers, the value from weather and climate forecasts is best realised when it is linked directly to on-farm decisions. As digital agriculture grows along with big data access we are seeing the emergence of more products that take a whole-of-farm approach or speak directly to a decision that needs to be made. A useful summary of the tools categorised by the agricultural domain is kept on the Climate Kelpie website (http://www.climatekelpie.com.au/).

The most prominent climate decision tools centre around making cropping decisions for the season ahead. Typically these tools use simulation models like APSIM, run with today's conditions and a range of previously observed weather to predict the outcome of this year's harvest. This assumes that this year's weather will unfold somewhere in the range of what has been observed before; they do not use dynamical forecasts. Examples of these include Yield Prophet (http://www.yieldprophet.com.au/yp/Home.aspx) and CropARM

[9] www.agforecast.com.au

(http://www.armonline.com.au) for cropping decisions and AskBill (https://www.askbill.com.au) for livestock decisions. In some tools the future weather possibilities are narrowed by choosing analogue years that align with similar phases of El Niño Southern Oscillation. These tools range in complexity and require different levels of engagement and information input by the user.

Looking beyond the farm gate, tools such as the adaptive value chains self-assessment tool (https://adaptivevaluechains.com/) uses climate data at a 5-km resolution to help understand and evaluate the climate risk exposure of a business or company. Using the tool, a national or multi-national company can map out its supply chain in Australia and look at the potential impacts a set of climate extremes might have on their supply chain. This is done using historical data and the company is given a risk-exposure report. For example, if you are a lettuce grower in southern Queensland that sends produce to NSW and have a supply chain with five nodes, then the report will help you understand where your greatest risk exposure is along that five-node supply chain. Companies and producers can also use the tool to investigate the impact of implementing different logistical scenarios.

### 6.2.4 Emerging trends and changes

#### Incorporation of climate models into decision tools

To date, agriculture productivity forecast products (e.g. wheat yield or pasture availability) have relied on historical climate patterns to describe the potential range of futures. New trends are emerging to incorporate climate-model forecasts into these agricultural estimates. This is occurring in Yield Prophet, SenseT pasture prediction, AskBill and the CSIRO Digiscape suite of products.

#### Personalising the information

Weather and climate forecasts have traditionally been provided as large maps or general information for a region. As the user becomes savvier there is demand for personalised information limited to the user's interest. For example, the user doesn't want to look at a map of the whole of Australia to understand the potential changes at their small town. New App developments are reflecting this with products like Yield Prophet Lite and The Yield delivering information for a specific town.

#### Paddock scale

There is a growing desire and opportunity for weather and climate information to be provided at the paddock scale to best facilitate decision making. This aligns with a need for a link to be developed between on-farm weather records and the forecasts. This trend is emerging in products such as The Yield but also is being considered by the developers of the forecasts at CSIRO and the BoM.

#### Whole-of-farm approach

While climate variability is fundamental to agriculture productivity it is not the sole consideration in on-farm management. Decision-support tools that only consider weather and climate information quickly become 'shelf ware' and the farm manager is easily swamped by numerous support tools that they must factor in to their decision making. Whole-of-farm approaches, that include climate considerations and others (such as market conditions), are now emerging as a clear preference to ease the load on the farm manager.

### 6.2.5 What needs to be done to get there

Improvements to the skill of weather and climate forecasts can continue to enhance our resilience in agriculture. Key actions where the most impact could likely be realised are:

i. improved measurements, assessments and predictions of extreme events such as drought, heatwaves, hail or frost

ii. increased understanding of the climate thresholds and tolerances of our vulnerable commodities (e.g. heat stress in dairy cattle; wheat yields under increasing temperature and decreasing rain; humidity/rainfall near picking times for fruit and vegetables)

iii. increased skill in making multi-week forecasts (10 days to 1 month) and an exploration of who can best use them, along with an integration of these forecasts into the existing decision-tool space

iv. forecasts of 'next years' climate for strategic on-farm decisions such as stocking rates and investments.

#### Climate integration and whole-of-farm tools

In many instances the skill of weather and climate forecasts is adequate for useful decisions to be made. Currently access to the forecasts is too complex or confusing for this to happen seamlessly for the farm manager. Effort needs to be invested in the steps from taking complex climate information and transforming it into the decision space. More climate and weather apps are not needed. Instead it would be prudent to explore how weather and climate APIs can be developed to feed into existing or emerging whole-of-farm digital agriculture products, as well as tweak outputs to relate directly to decision making (see Table 4 for examples).

**Table 4: Evolution of thinking on forecasts, going from the current state to a possible future state**

| CURRENT THINKING | NEW OR EMERGING THINKING |
|---|---|
| **Daily rainfall forecast** | Forecast of good spraying conditions |
| **Probability of earlier or later than median wet season onset** | Probability of green-date occurring in any given month in the seasonally wet-dry tropics |
| **Seasonal rainfall forecasts by Australia wide map** | Location-specific seasonal rainfall forecast with nitrogen application advice |
| **Madden Julian Oscillation (MJO) phase forecasts** | Multi-week rainfall forecasts by location interpreting MJO phase and probability |
| **Observed NDVI** | Forecast date of pasture senescence (peak quality) |

#### Paddock-scale forecasts

As climate and weather forecasts become skilful enough to be useful, our next hurdle is to translate this information to the paddock scale. Increasing resolution of models is one solution that will occur over time with increasing computer power. At the same time, consolidation of available weather datasets into a high-resolution modelled observation grid along with the establishment and inclusion of more weather, water and land sensors needs to continue. In parallel, coordination of this data is needed along with guidance on IP and ownership issues. An extensive observational database will enhance our ability to provide the most skilful weather and climate information to the end user.

### New measures of forecast value

The goal of improving future weather and climate information has been primarily to increase profit and productivity. These are clearly measurable and impactful quantities which make easy targets for researchers. However, it is important to recognise that not all climate information is used for this end yet still adds to the greater good and resilience of Australian agriculture.

Emotional resilience in an environment of high uncertainty underpins the wellbeing of rural communities. To this end knowing there is a higher chance of a devastating frost this week allows the grower to prepare and talk with friends rather than waking up unexpectedly to a ruined crop. Even seemingly inconsequential decisions such as 'will there be an early break in the monsoon, or should I just take the family on holiday' may not appear in the profit columns but do add to the greater wellbeing and resilience of the community. Investing in ways to understand and measure these implications of weather and climate forecasts would provide new targets for researchers to add a layer of value that isn't so apparent.

## 6.3 Remote sensing imagery

### Case Study: measuring sugarcane yield

Photographer *: Gregory Heath on January 01 2002*

Jason farms a 100 ha sugar farm in the Herbert River. Like all growers, he has no choice which mill his cane is delivered to, but by sharing data about his production system with the mill, he wants to ensure that he harvests his cane in such a way that sugar production at the mill is maximised, so as to maximise his return. Meanwhile, in addition to maximising cane supply, the mill also wants to maximise sugar production. Through analysis of block yields over several seasons, there is good local knowledge as to the inherent variability in yield at district scale; some areas are inherently low yielding, whilst others are higher yielding. Jason's farm typically yields close to the district average. Through locally agreed changes to the harvest roster, the mill now directs the harvest based on the known spatial variation in yield, supported by seasonal climate data collected from a network of weather stations throughout the district, and the yield predictions derived from remotely sensed imagery. Because this season is a dry year, the mill has harvested the low yielding/high sugar areas early in the season; the low yielding wetter areas are being left until the end, to allow yield at harvest to be optimised in the high and mid-range yielding areas.

New hyperspectral imagery available from satellites indicates at district scale, which areas have cane with the highest sugar content this year and so can be used by the mill to direct the harvest to optimise yield and CCS. However, Jason knows that his farm is variable at the within-block scale; in addition to focussing his harvest to optimise the yield of plant and first ratoon cane in those parts of his blocks which are the highest yielding (he has been yield mapping for several years), in partnership with his neighbours, he has bought a drone fitted with a miniature version of the same hyperspectral sensor as is available by Satellite, so that he can map predicted CCS in his cane prior to harvest at a resolution of 50 cm. Through discussion with the mill, Jason, along with other growers in the district, will harvest this high yielding, high CSS cane on an agreed day, so that the mill can be adjusted so as to maximise sugar extraction from this high CCS cane. In addition to getting a good return due to high yield and CSS, Jason is also paid a premium by the mill in return for the partnership arrangement.

His cane is yield monitored during harvest and the harvester also has on-the-go-CCS sensing. Each bin has an RF ID tag which connects via bluetooth to the harvester, so that once delivered to the mill, the provenance of each harvested bin and its production details are known; both the harvester and the haulouts have machine guidance to minimise soil compaction. The data collected by the harvester are downloaded directly to the cloud. On non-harvest days, Jason and his agronomist can download the maps of yield, CCS and tonnes of sugar produced and see how these compare with previous seasons, with the predicted yield and CCS and also with his soil and DEM. These data are valuable inputs to his decisions about further ratooning, moving to a fallow and thence replant, and, in conjunction with his high resolution soil data, decisions as to which varieties he should plant next and whether drainage or other land preparation works (land planning) are warranted.

Box 5: A case study on monitoring sugarcane yield

### 6.3.1 **Introduction**

#### What is remote sensing?

Remote sensing (RS) is the process of acquiring information about Earth by scanning it using ground, aerial or satellite-mounted sensors. Ground, aerial and satellite systems provide information over increasingly large areas, and different technologies of sensors are used to measure different properties. The device the sensor is mounted on is typically called the platform. Examples of ground-based platforms could be a tripod, a quad bike or a tractor. Aerial platform examples include aeroplanes, drones and blimps.

### Why and how it is of value to agriculture

Measurements provided by sensors mounted on remote platforms are used to infer canopy parameters such as vegetation cover, biomass or leaf chlorophyll content. RS can also be used to estimate other characteristics of the surface of interest to agriculture such as soil and regolith properties and soil moisture. The applications of RS in agriculture include:

- crop-type mapping, crop-yield estimation
- clearing and land cover change detection
- pasture biomass, quality and growth estimation
- drought and resilience/health analyses
- irrigated-area mapping, soil-moisture modelling, transpiration and crop water use
- bare-soil mapping for soil health, soil carbon and erosion potential assessments
- crop/pasture stress, including nutrients, water deficiency and pests
- precipitation estimates (particularly in areas with low rainfall gauge density)
- soil moisture
- ground cover monitoring (of bare, green, and non photosynthetic vegetation) for modelling and reporting on wind erosion and hill slope erosion.

### How it is acquired

Remote sensing does not observe any of the biophysical properties listed above directly. Rather, sensors typically detect the amount of radiation reflected from the sun by the surface (optical), emitted directly from the surface (thermal, microwave) or reflected by the surface from an emission from the same sensor (radar and Lidar). Once detected by the sensor the radiation has to be converted to the property of interest. This typically involves a series of pre-processing steps to minimise contamination by atmospheric factors (e.g. aerosols, water vapour) and terrain factors (slope). The last and most important step is to estimate the property of interest, which is done using a model. For example, a very typical product obtained from optical sensors is the normalised difference vegetation index (NDVI, the ratio between the near infrared and red reflectances). The NDVI is then used to infer vegetation cover and leaf area index via empirical models, and incorporated into methods for estimating crop yield, type or stress.

When collecting data, the practical aspects may be summarised as ‘when, what, how much, and how often?’ The ‘when’ may be the time of day or season, ‘what’ may be soil moisture or physical plant properties, ‘how much’ may refer to the geographic extent, and ‘how often’ could be hourly/daily or monthly measurement.

The characteristics of the platform and sensor influence what is possible. For instance, the orbital characteristics of a satellite determine overpass frequency (how often) and spatial coverage extent (how much), and the sensor what property is being sensed. There is typically a trade-off between temporal (how often), spectral (how many 'colours' or wavelengths are observed), and spatial resolution – the higher one dimension is, then the lower the others typically are. Some sensing technologies (for example Synthetic Aperture Radar – SAR) can see through clouds and some cannot (for example 'optical' sensors).

For satellite-based optical sensors, the overpass frequency is an important characteristic of RS imagery – particularly for agriculture applications – as it determines how frequently a location can be measured, and this has shaped the use of RS over the past four decades. The more frequently a satellite acquires imagery over a location, the higher the chance of obtaining a cloud-free image and hence an observation of what's on the ground. If a geographic region or season is very cloudy, then cloud-free images of the ground may be few or not possible, or the timing not guaranteed, using optical sensors. To improve the chances of seeing the ground, satellites with a higher frequency of overpass are used with the trade-off that the spatial resolution is reduced. This high frequency imagery has a better chance of seeing the ground but generally can't detect small spatial features. Historical archives of Earth observations of agricultural fields are predominantly observations from optical instruments. Current observations are compared with historical information when information on change is required.

### 6.3.2 **Current state**

The most successful and widespread use of RS in agriculture has utilised optical imagery from several satellite platforms that provide complete spatial coverage (sometimes referred to as being wall-to-wall coverage). The sensors on these platforms are predominantly what are called broadband instruments, and they record reflected light aggregated into several spectral regions, roughly corresponding to what we observe as red, green and blue. They also record information in the infrared region of the spectrum which is not visible by the human eye. Such imagery is often free of charge. Instruments that record reflected radiation at hundreds of parts of the electromagnetic spectrum also exist, but these typically image over smaller areas due to data volume and other technical factors.

Many useful applications in agriculture of hyperspectral or radar imagery have been demonstrated, but the low repeat frequencies, coarse spatial resolutions, and/or limited geographic coverage that are typical of these sensors have, historically, limited their use in agricultural applications. This is starting to change, for example the European Sentinel-1 satellite includes a C-band SAR sensor and has a revisit time and geographical coverage useful for agriculture and it's particularly useful for tropical regions with high cloud cover. Optical, multispectral sensors will nevertheless continue be dominant in the RS-agriculture space.

The primary uses of broadband RS imagery in agriculture have been in the detection and mapping of classes of land cover of interest, or the change in land cover responses over time, or a combination of the two. For example, the detection of 'greenness' – the amount of ground covered by green foliage and its change over time – is a staple use of RS imagery. This is strongly correlated to foliage cover, fPAR (the proportion of incoming solar radiation absorbed by foliage), photosynthesis rates, and leaf area index (LAI, but only when LAI is $<3$). In addition to these quantitative biophysical variables, RS has also been used extensively to estimate qualitative variables (such as vegetation or crop-type mapping, tree clearing and soil colour) as well as for providing relative measures (such as greenness anomalies used in drought monitoring). Measures of land surface temperature have also been used, which are related to transpiration and evaporation, and so have been used to study water use and irrigation.

There have been three dominant workhorses in the RS-agriculture space over the past three to four decades: Landsat, AVHRR and MODIS.

Landsat is the oldest Earth observing mission and has an extensive history of use in agriculture. It started in the 1970s, but really came into widespread use around 1982, and is still going. The US Government maintain a Landsat Data Continuity Mission, ensuring observations into the future. There has been a succession of Landsat platforms which have all carried essentially equivalent sensors, with the latest being Landsat 8 carrying the 'OLI' sensor. Landsat imagery provides wall-to-wall coverage once every 16 days and at ~30 m resolution. This imagery is excellent for observing paddock and sub-paddock-scale features possibly every 16 days bar cloud cover. The 16-day repeat frequency can be problematic in obtaining multiple ground cover observations in regions or seasons prone to cloud, for example in rainfed agricultural regions. Assessment of trends and dynamics of cover in these regions cannot be guaranteed.

The next workhorse is commonly referred to as AVHRR (advanced very high-resolution radiometer) imagery, which is hosted on the US National Oceanic and Atmospheric Administration (NOAA) series of satellites. AVHRR imagery has been continuously acquired since 1982. It has a daily overpass providing a high probability of observing the ground within a given time period. It has consequently been the preferred imagery for analysing vegetation dynamics and trends across large areas such as regional, continental, or planetary studies. AVHRR imagery has a resolution of around 1100 m, although a subsampling routine was applied earlier in its lifetime to reduce the data volumes.

Early in the new millennium, the MODIS mission started providing new-generation land-surface imagery of reasonably fine resolution (250 m), high overpass frequency (two per day) and improved data quality (self-calibration capabilities). A MODIS sensor is mounted simultaneously on two platforms – the TERRA and AQUA satellites – which have been operating since 2001. MODIS imagery has generally replaced AVHRR for applications that don't pre-date 2001. However, in many applications that require fine spatial resolution (paddock and sub-paddock), Landsat is still the imagery of choice.

### 6.3.3 **Emerging trends and changes**

The use of RS, in general, is currently undergoing rapid transformation, and this is true in agricultural applications. This is due to a combination of advances in multiple areas including in our abilities in sensing, computing, transmitting, storing and analysis.

New and increasing numbers of RS sensors and platforms are becoming available, most importantly those from the national space agencies (government), the private sector, particularly the miniaturised satellites and proximal sensors (such as sensors mounted on drones and unmanned aerial vehicles or UAVs).

Within the public sector new-generation RS sensors are making it possible to have both high spatial resolution and high repeat frequencies, making paddock and sub-paddock-scale analyses of temporal dynamics and change feasible. This is largely due to the Copernicus programme of the European Space Agency (ESA), which is launching the Sentinel series of satellites.

The Sentinel-2 satellites (A and B) were both launched by March 2017. They are high resolution (10 x 30 m), high frequency (≤5 day) optical sensors. Effectively, these sensors combine the strengths of Landsat and MODIS sensors and allow the traditional methods and applications to be continued but simultaneously at sub-paddock scale and with sub-growing season temporal precision.

The Sentinel-1 satellites are C-band radars, which operate at wavelengths responsive to plant structure and moisture. The first Sentinel-1A was launched in April 2014, followed by the Sentinel-1B in April 2016. There are two more similar satellites planned in the near future. For the first time for a radar sensor, this is providing frequent (≤6 day) and high resolution (10 x 30 m) imagery which is not affected by cloud cover. This is providing completely new capabilities and applications, particularly in areas highly affected by clouds such as the tropics. For example, crop monitoring, particularly rice across India and SE Asia, relies heavily on radar imagery.

While these new sensors will provide new RS capability, Landsat and MODIS imagery will continue to be important data sources, especially where historical context is required. To benefit from the strengths of each of these, 'blending' activities are becoming more common where the spatial detail of Landsat and the temporal detail of MODIS are combined to produce a synthetic high-resolution/high-frequency information product. Integrated application of RS in agricultural applications is becoming more common. Multiple data sources (often of the same variable) are combined or assimilated using models to produce a best-available representation or estimate of a particular variable of interest – for example, crop yield or soil moisture.

Associated with this trend is the emergence of the use of RS imagery in a predictive capacity, rather than just the prospective (historical) capacity that has traditionally prevailed.

Another important trend in the RS space is the rapid increase of the private-sector involvement in the launch and operation of satellites for Earth observation. The private sector had traditionally operated large and costly satellites providing very high-resolution imagery, for example the WorldView and RapidEye systems. The use of such imagery by the agriculture sector has been very limited, mostly due to the high cost associated with acquiring repeated imagery. This situation is changing rapidly due to the appearance of much cheaper and small satellites (also referred to as miniaturised satellites, 'nanosatellites' or 'cubesats'). Planet, BlackSky and Satellogic are examples of companies investing heavily in launching constellations of such small satellites and tapping into the mining, agriculture, and transportation industries. The imagery provided by these mini-satellites is generally of lower quality than the traditional sensors such as Landsat or Sentinel-2, but as these satellites are much cheaper to launch and operate, the biggest advantage is that they provide much more frequent revisit times (e.g. daily) with generally higher spatial resolution. This is a very active sector and likely to gain a much bigger role in the near future.

In addition to the improvements in sensors and platforms, an important current trend in the RS area are the improvements in data storage and analytics facilities, linked to big data and cloud computing. This is rapidly changing the way in which a researcher or GIS analyst works. Traditionally the steps taken for developing an application or even analysing a farm involved a number of laborious and costly steps including downloading and pre-processing large amounts of data before any analysis could be made. These steps are very time consuming, need a relatively high level of skill (i.e. a trained person) and also need a fast internet connection and a powerful CPU with large amounts of storage available. The larger the area and/or period of time of the analysis, the larger the effort involved. This is becoming a thing of the past.

Several initiatives are doing all the steps listed above for all the imagery archive and providing users with large amounts of RS data ready to be used in analyses. In addition, many of these initiatives provide computing resources where the users can run and test their own algorithms, largely decreasing or eliminating the need to invest in computing resources. Examples of such facilities include the Open Datacube initiative and Google Earth Engine. Even the private providers, such as Planet mentioned above, are shifting their business models from one where they sell individual imagery to one where they offer access to a cloud platform where the user can not only access the imagery but also apply standard processing algorithms or even develop their own and run them in their own servers (see for example https://www.planet.com/explorer/). These initiatives are also facilitating the use of RS data and derived products and applications in mobile platforms (tablets, phones) and starting to make their way into the farmer's pocket to consult in real time the status of her crops and pastures.

### 6.3.4 **Desired future state**

The trend towards increasing numbers of sensors and platforms with higher spatial, temporal and spectral resolutions will result in increasing data volumes. The future has to accommodate the flow, storage and processing of substantial volumes of image-based and other spatial data.

The emergence of new data streams, particularly from proximal-sensing technologies (such as drones and UAVs, and ground-based sensor networks) is expected to accelerate. It is easy to imagine a future where property (or a collective of properties) has its own fleet of autonomous drones that launch several times a day to provide high-accuracy, high-resolution sensing of the full estate. These will combine with ground-based and animal-based sensor networks. RS imagery will then be just one part of a whole, integrated information ecosystem that provides seamless, real-time and management-relevant information products.

Big data analytics and data assimilation schemes will be the core of such an information ecosystem. These will also involve automated data analytics, artificial intelligence and fully integrated user-interface networks.

A key characteristic of these information ecosystems – one that is in contrast to current practice – is predictive capacity. Real-time assessments will be the bare minimum standard in information; predictions into the near and medium future will be the main focus.

There will be an increase in 'bespoke' satellite missions that have specific foci (as opposed to current missions which are generalist). This includes the current trend in micro-satellites that are cheap and provide full and rapid coverage – but only for a narrow and specific set of observations. This also includes specialist missions, such as ESA's 'biomass' and 'fluorescence explorer' missions, which are sensors tailored to the observation of tree biomass and photosynthetic activity, respectively.

### 6.3.5 **What needs to be done to get there**

Investment into this *information ecosystem* will be a critical step into the future. This means research into, in particular:

- the evaluation of new sensing systems, the information they may provide, and the value that they offer to the agricultural industry
- reception, storage and workflows of the data such that near-real time and predictive capacity can be utilised (timeliness of results)
- how to optimise the integration/assimilation of multiple RS data streams, and how to optimise the integration/assimilation of these with proximal sensors, sensor networks, personal technology, and data analytics
- predictive modelling capacity that is built around the information ecosystem.

RS imagery has been and will be increasingly used in digital agriculture applications. However, remotely sensed imagery that is appropriately processed is not easily accessible and interpretable to those wishing to use it for digital applications. Our recommendation is to consider revamping how publicly available imagery is made available. Moreover, the coverage, frequency, access to and ease of use of the emerging satellite layers (e.g. Sentinel, cubesats) need to be assessed and industry-wide platforms created for these layers to be accessed and used. There is also a need to develop optimal metrics for prediction in Australian systems.

#### Changes that RDCs can make

RDCs should be entrepreneurial, with appropriate management of IP and use these two mechanisms to accelerate the availability of digital technologies.

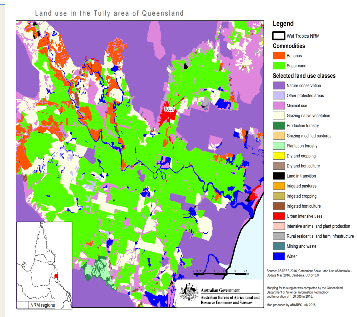
Agricultural data has significant potential to provide value to governments, support industries, industry bodies, RDCs researchers and producers. But the lack of infrastructure, mechanisms to share value and trust are significant impediments to this occurring. Another significant impediment is that value may not accrue until a reasonable proportion of producers are involved. We recommend a platform for owners and users of agricultural data to exchange, market and value-add data for a variety of end purposes. We recommend exploring the feasibility of an industry-good platform, with appropriate business model, that could catalyse data exchange, along with appropriate protocols around use and rights of owners.

#### Changes that RDCs can influence

RDCs should maintain a proactive engagement with the government sector and ensure that existing and future initiatives in Earth observation provide opportunities and deliver value for the agriculture sector. For example, the agriculture sector will greatly benefit from Geoscience Australia’s Digital Earth Australia initiative but the specific needs for monitoring crops, rangelands, pastures and forests need to be kept in the forefront. Similarly, the recently announced Australian Space Agency will contribute to the improvements in Earth observation infrastructure but the voice from the agriculture sector needs to be heard.

## 6.4 Land use

### 6.4.1 **Introduction**




**Case Study: Panama disease tropical race 4 (TR4)**

Panama disease Tropical race 4 (TR4) is the name given to the strains of the fungus *Fusarium oxysporum* f. sp. *cubense* (*Foc*) that cause Fusarium wilt (aka Panama disease) in Cavendish banana cultivars. The strain was first identified in Australia near Darwin in 1997 and managed since by strict quarantine. It has significant production and market access impacts. Recently TR4 was detected on Cavendish bananas in Queensland on a Tully farm in March 2015 with another case confirmed on a nearby property in July 2017. The pathogen is persistent in the environment and has a wide host range. In Queensland prompt reporting of plants with suspected symptoms of Panama disease is a legal requirement, and critical to successful containment of the disease.

Disease spread is fundamentally a spatial process. Spatial information about banana plantations is critical to understanding sampling protocols to delimit the extent of the incursion. Spatial information also underpins assessments of the most efficient and feasible containment strategy. Biophysical and anthropogenic dispersal processes can potentially be modelled using weather and hydrological information and knowledge of the hosts and epidemiology of the disease. Road networks and population information can be used to quantify anthropogenic vectors and assess management strategies. The combination of all these data sources leads to better informed decision making during incursions.
https://www.daf.qld.gov.au/plants/health-pests-diseases/a-z-significant/panama-disease2/panama-disease

Mapping of banana plantations across Australia has been funded jointly by state/territory agencies and the Australian Government Department of Agriculture and Water Resources through the Australian Collaborative Land Use and Management Program

**Box 6: A case study about monitoring disease spread**

Information on land use has been of interest since the early days of settlement. Land use information allowed people to understand opportunities and plan businesses. It helped governments to develop regions and learn and respond to the novel Australian environment.

Land use information is potentially useful to industries and governments for a range of purposes:

- biosecurity: land use information can be used to support market-access requests, plan and execute effective responses to incursions of pests and diseases, and plan effective surveillance strategies (see Box 6)
- industry planning: knowledge of the location and extent of industries can support industry planning, government development of infrastructure and commercial providers targeting products and services
- hydrological and water quality modelling e.g. modelled estimates of water quality reaching the Great Barrier Reef from land used for agriculture are underpinned by land use mapping
- strategic assessment: land use data supports better regional planning and policies.

Initial land use information was qualitative and conceptual. While initially anecdotal, the development of agricultural industries provided an information base to understand the productive capacity of regions and the nature of enterprises.

The development of more dynamic and spatially explicit products was enabled by the availability of RS data and GIS technology in the 1990s. These developments provided a cost-effective means of acquiring data over regional areas and information processing systems that could store and perform analytics based on this information.

Australia's first coordinated approach to land use mapping was funded by the National Land and Water Resources Audit and ran from 1997 to 2008. This funded the development of a national-scale map based on blending continental satellite information with ABS agricultural statistics. In-parallel, catchment-scale products were initiated through NLWRA funding through collaborative work between the Australian government and state/territory government agencies based on remote sensing, ancillary state data sets and field observations for quality assurance. These products were based on agreed national mapping standards and a land use classification scheme (ABARES 2011, 2015a, 2016). They are updated in a coordinated way as new data and funding becomes available (http://www.agriculture.gov.au/abares/aclump/land-use/data-download). Figure 4 shows a recent national land use map of Australia.

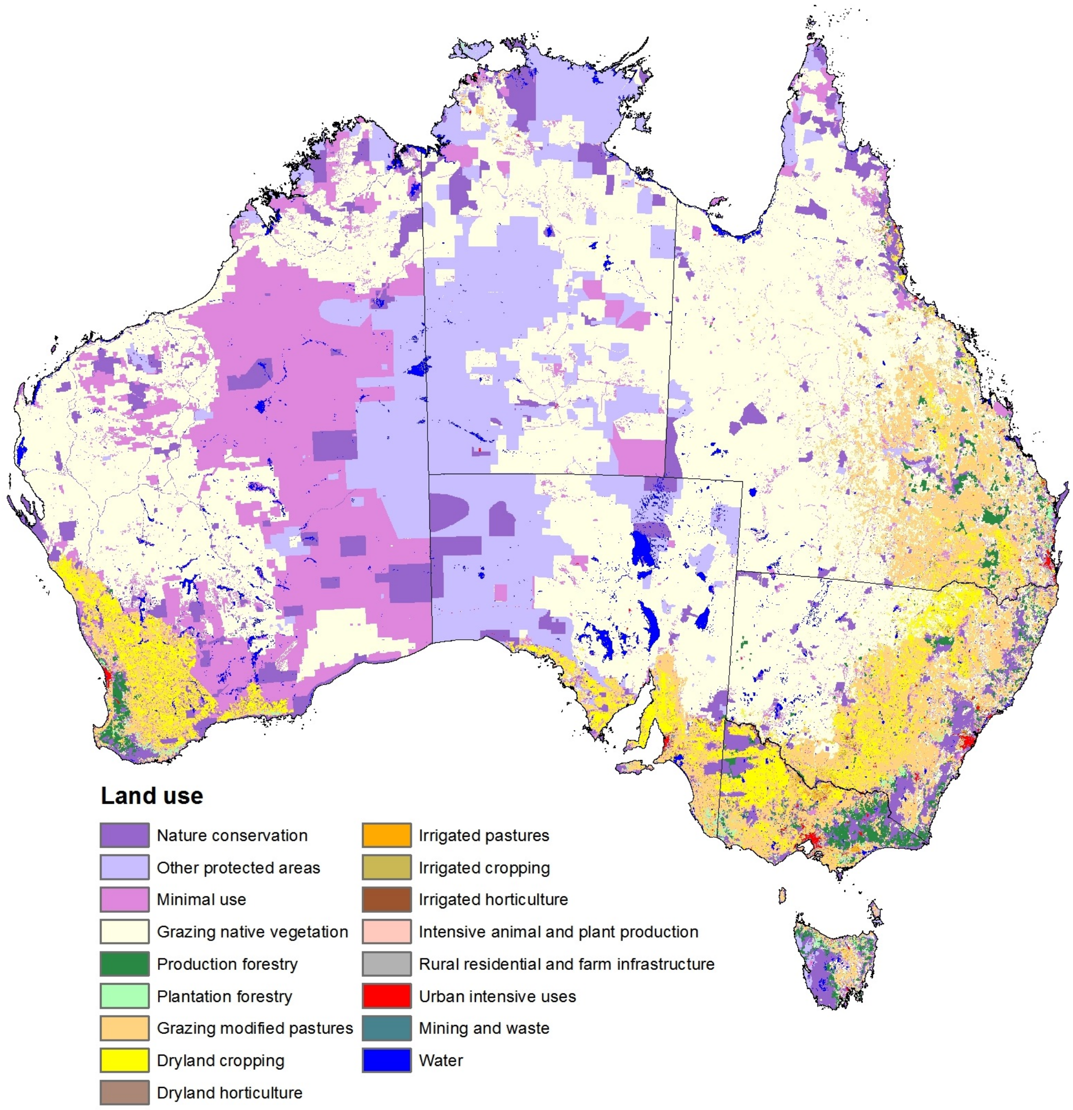



**Figure 4: The national land use map of Australia, 2010–11**

### 6.4.2 **Current state**

Land use datasets are products of the Australian Collaborative Land Use and Management Program (ACLUMP). The Department of Agriculture and Water Resources and the relevant state government agencies are the custodians. There are currently two major land use products (ABARES 2015b):

- catchment-scale land use data – Detailed mapping is undertaken by state and territory agencies according to national guidelines. Land use is classified by its prime use using a hierarchical structure. This allows land uses to be attributed as broad classes down to individual commodities (e.g. bananas, avocadoes, mangoes) where possible. The data are then compiled and published annually to create a composite national dataset of the most recent mapping. The catchment-scale land use mapping coverage is available for mixed dates (mapping will be less than five years old for about 80% of the continent) at a scale that varies according to the intensity of land use activities and landscape context.

- national-scale land use data – A modelling approach is employed to allocate agricultural land use based on satellite data, the ABS agricultural statistics and control points of known land uses. The dataset is produced every 5 years following the release of the Australian Bureau of Statistics Agricultural Census, providing a national-scale distribution of Australia’s agricultural production systems with a resolution of 1.1 $km^2$.

### 6.4.3 **Emerging trends and changes**

Digital technologies are creating a number of opportunities for more cost-effective land use mapping. First, new satellites, as detailed in Section 6.3 are providing additional information sources to improve both catchment-scale and national-scale mapping products. In addition, new potential sources and streams of ground-truth data via administrative processes or digital agriculture platforms have the potential to significantly improve current products by improving classification algorithms. The use of industry-supported data collection is also a significant opportunity (see Box 7).

A potential challenge is the continuity of the ABS agricultural census data in its current form. As the ABS seeks to reduce the burden on respondents and be more efficient there is active consideration of alternative sources of information to the traditional survey census (ABS 2015). These changes need to consider impacts on the quality of derived products.

There are also now a range of international programs developing land use mapping products within particular countries (US, UK, Europe) and globally (USGS).

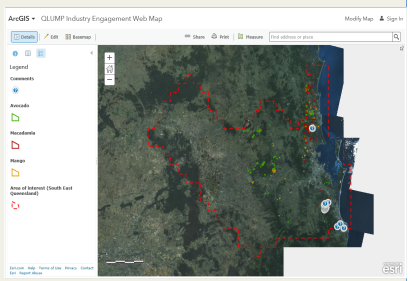
## Case Study: Land use mapping through industry collaboration

Information on the spatial distribution of industries is critical for a range of purposes. It can support applications for market access as it underpins the knowledge base about an industry's extent. It can support the management of pest and disease incursions. It assists governments to access the impact of natural disasters, speeding up natural disaster response. It also allows better management and development of regional infrastructure and provides information to digital providers about the location and extent of industries.

The Australian Mango Industry Association, Avocados Australia and the Australian Macadamia Society have collaborated with universities, government agencies and private industry to develop an interactive web map of mango, avocado and macadamia tree crops across Australia. This mapping integrated satellite information with industry and government land cover data, regional surveys and on-ground evaluations to map the location and area of Australia's commercial mango, avocado and macadamia orchards.

The mapping uses analytics as well as digital technology to allow industry members to contribute information about orchard locations as well as feed back information on the validity of the mapping. It is a good example of cooperation between the private and public sector to achieve benefits for all parties.


Source: : http://www.industry.mangoes.net.au/resource-collection/2017/7/11/mapping-australias-orchards-for-improved-industry-biosecurity-and-natural-disaster-recovery




Source: http://www.industry.mangoes.net.au/resource-collection/2017/7/11/mapping-australias-orchards-for-improved-industry-biosecurity-and-natural-disaster-recovery

**Box 7: A case study about land use mapping through industry collaboration**

### 6.4.4 Desired future state

There is significant demand for improvements to products to provide better resolution, accuracy, timeliness, and land use change. Improvements in accuracy will come from better quality information sources. Improved timeliness extends to the ability to make within-season assessments of land use. These would be valuable to predict yields and use this information to inform logistics and marketing. Land use change is important to inform market trends and regional policy implementation and assessment. The challenge with this is that without extremely accurate static products it may require a dedicated product with associated costs.

Australia already has the National Committee on Land Use and Management Information (and its associated program ACLUMP) that provides coordination and standards to underpin the production of products. While this group exists, and has underpinned the development of major products, a number of significant impediments remain. The impediments to reaching this future state are both technical and institutional. The technical challenge is to find better ways of accessing and integrating information. Digital agriculture platforms, citizen science (via public and/or industry members), administrative information such as R&D levies and improved RS products are all potential new data streams that can significantly improve the timeliness and quality of land use information in the future. The challenge is to integrate these sources efficiently. This requires the use of machine learning and analytics techniques to automate it.

The institutional issue is that while there are a wide range of potential beneficiaries that can get value from this data, the costs associated with developing and operationalising products are too large to be met by a single user. Development of new products requires cooperation between all potential beneficiaries. The products also depend on state and commonwealth funding to maintain the infrastructure needed to update and disseminate the information. This would also be improved by having industry engagement.

R&D corporations can assist development of these products by considering their value in industry planning and biosecurity preparedness. They can support initiatives and projects which facilitate the acquisition of relevant data and the development of products that support industry management and biosecurity.

## 6.5 Property boundaries

### 6.5.1 **Introduction**

Within the context of land ownership within Australia, the term 'property' can mean a number of different, but related, things. Firstly, in a legal sense, land is divided into uniquely identified parcels over which individuals have a government-guaranteed title and associated property rights. Secondly, collections of, usually, adjoining parcels, owned and/or operated by a single enterprise are often referred to as a property (e.g. 'Rockleigh', 'Stoneyview' etc). This, more common, concept of 'property' has no legal basis but is used for identification and by local government for the purpose of levying rates.

Property boundary information is important in agriculture for a number of reasons. The legal boundaries provide a known location and extent of land holdings and underpin the valuation and taxation of properties. The physical boundaries of properties and paddocks are needed to support automated management such as the collection of data by drones, auto steer, variable rate fertilising or yield analysis.

For the purposes of this section, both uses of the term 'property' have been explored.

### 6.5.2 **Current state**

Information about land ownership and associated property boundaries has been important in Australia since early settlement. While the initial land systems, imported from Britain involved grants and deeds which had minimal publicly available data, this changed with the development of Torrens Title system in 1858 and its subsequent adoption across all Australian jurisdictions. Under Torrens titling, the government maintains a register of all land holdings and guarantees title to those listed on the register. Key information included in this register is identification of the parcel of land over which the title is guaranteed. In Australia, this identification is the form of a reference to a lot on a registered plan. This plan records the dimensions of the land and its boundaries. To change the boundaries of a parcel of land, a new plan must be prepared and registered.[10]

The collection of all registered parcels of land is known as the cadastre. All jurisdictions have in place programs to maintain a digital, spatial representation of the cadastre. These databases are referred to as digital cadastral databases (DCDB) and vary in content and structure between jurisdictions.

These databases are combined by PSMA Australia, to produce their CadLite[11] product which provides spatial representation and information about legal land parcels across Australia. This dataset is a digital representation of cadastral boundaries. Therefore, the accuracy of cadastral data as a representation of property boundaries depends on a range of technical and historical issues.

Unlike cadastral boundaries, there is no official register of 'rateable' properties apart from those maintained by local government (or equivalent) for their purposes. The Cadlite product includes a 'Property' dataset that reflects the boundaries of these 'rateable' properties.

Property boundaries (both cadastral and 'rateable') and physical infrastructure such as fence lines have no formal relationship. Legal boundaries are based on the description on the registered plan. Often physical marks are placed at the time of original survey in order to enable these boundaries to be re-established in the future. These marks are reflected on the registered plan. However, these marks can disappear over time. Fences, may or may not coincide with boundaries but do not mark a boundary unless the registered plan indicates this.

Physical property boundaries are the reality of the land's management. While the legal boundaries underpin this, the relevant land law determines the rules of land development and access. There are also paddock boundaries within properties.

PSMA also produce a national geocoded address dataset. This is generated by combining a range of incomplete sources and using this to infer real addresses. This dataset is the closest Australia has to a register of property addresses.

### 6.5.3 Desired future state

Legal property boundary information is a core government function and is already well developed and has strong legislative requirements.

There is no register linking parcels, properties and legal ownership. This could be useful to automatically integrate remote monitoring to properties, and allow better understanding of industry structure. We note that information about physical property boundaries will increasingly be collected as part of digital agriculture. The value in sharing this information is still to be determined.

---

[10] https://en.wikipedia.org/wiki/Torrens_title

[11] https://www.psma.com.au/sites/default/files/cadlite_product_description.pdf

# 7 An agriculture register of online datasets

The data register presented here was created via desktop research, workshops and from individual interviews with experts and industry providers (see Methodology for details). The purpose of creating this data register was to elucidate the available datasets that may be relevant to Australia's agricultural industries. Each entry of the data register has a title, description, custodian, source, licence and format. Each entry also has a link to an OzNome entry that has a more complete set of attributes. Table 5 shows how the register was generated by tagging and keyword searching.

**Table 5: Number of datasets at each iteration of the keyword filter processes**

| DATASETS | COUNT | % OF KN | % OF POTENTIAL |
|---|---|---|---|
| **All KN** | 125,819 | | |
| **Soil (potential)** | 899 | 1% | |
| **Soil Register** | 254 | | 28% |
| **Imagery (potential)** | 786 | 1% | |
| **Imagery Register** | 275 | | 35% |
| **Boundary (potential)** | 2,854 | 2% | |
| **Boundary Register** | 878 | | 31% |
| **Weather/Climate (potential)** | 9,339 | 7% | |
| **Weather/Climate Register** | 2,777 | | 30% |

The data register is organised into four separate focus areas: soils, weather and climate, imagery, and land use and boundary information. In forming the register, we've had to assess the quality, usability, and integrity of the datasets. We have done this through OzNome's self-assessment star-rating system (see Methodology) and via a panel of domain experts. The 5* OzNome Data tool (available at http://oznome.csiro.au/5star/) allows users to carry out a self-assessment based on five qualities of data – findable, accessible, interoperable, reusable and trusted.

To access the complete list of datasets, visit p2d.csiro.au.

The Knowledge Network[12] website holds a large number of links to datasets relevant to the major rural sectors. Experts scanned the potential datasets to those that they considered useful, reducing the potential datasets to major key datasets for each sector.

Only the major datasets are listed below in each of the relevant sections.

Almost all of the major datasets quote some version of the Creative Commons Attribution (CCA) in their metadata or on their websites. CSIRO's Digital Access Portal (DAP) for which OzNome is listed in the register has having no licence information. However, the CSIRO DAP refers to a licence as 'CSIRO Data Licence', but does not provide any details (no URL) about

[12] kn.csiro.au

what that means. Another is NCI[13] that does not have any licence information. BoM have not provided metadata although they have a page detailing copyright.

Many of the source sites provided one or more APIs for developers to access their datasets. Some provide web-based tools to view the data as tables or as a GIS layer.

The OzNome[14] team is exploring the use of the Technology Readiness Level (TRL) and Investment Readiness Level (IRL) metrics, and supplementing them with the Community Readiness Level (CRL) metric as means of communicating levels of technical, business and social readiness/maturity. The Oznome project argues that TRLs and IRLs are necessary for testing demand for a certain technology solution but lacks the integration of a social dimension that is often the case with shared infrastructure.

## 7.1 Soils data

A summary of the major datasets in the soils area is given in Table 6. Of the datasets listed, the Australian Soil Resource Information System (ASRIS) is the most well-known (part of the csiro-dap source listed in Table 6). ASRIS provides online access to the best publicly available information on soil and land resources in a consistent format across Australia. It provides a hierarchy of mapping units with seven levels of generalisation. The level of detail depends on the survey coverage in each region. The data for the ASRIS Level 5 (finest scale) soil units can be downloaded in an APSIM-compatible format for crop modelling.

**Table 6: Major soil datasets within the register**

| Dataset | Description | URL | License | Format |
|---|---|---|---|---|
| Soil and Landscape Grid of Australia | 1. **National Soil Attribute Maps**, which are combinations of the;<br>2. **Australia-wide 3D Soil Attribute Maps** derived using consistent data mining-kriging models and<br>3. **Regional Maps** for parts of Australia, derived using disaggregation and data mining modeling. | https://data.csiro.au/dap/ | Creative Commons Attribution 3.0 Unported Licence | GeoTIFF |
| Australian Soil Resource Information System | ASRIS provides online access to the best publicly available information on soil and land resources in a consistent format across Australia. It provides information at seven different scales<br>• The upper-three scales | https://data.csiro.au/dap/ | Creative Commons Attribution 3.0 Unported Licence | GeoTIFF |

[13] nci.org.au/

[14] research.csiro.au/oznome/

| | | | | |
|---|---|---|---|---|
| | provide general descriptions of soil types, landforms and regolith across the continent.<br>• The lower scales provide more detailed information in regions where mapping is complete. Information relates to soil depth, water storage, permeability, fertility, carbon and erodibility. Most soil information is recorded at five depths.<br>• The lowest scale consists of a soil profile database with fully characterised sites that are known to be representative of significant areas and environments. | | | |
| State soil information systems and tools e.g. NSW eSPADE, Soil and Land Information (SALI), Qld-globe, Vic Soil Info System<br>VSIS, Tas DPIPWE LIST map, WA MySoil | eSPADE provides access to soil profile and soil map information published by the NSW Office of Environment and Heritage, including map data, reports and images, primarily sourced from the NSW Soil and Land Information System (SALIS).<br>VSIS: A spatial map layer of soil type (Australian Soil Classification) for Victoria. The harmonised map consists of 3,300 land units (totaling about 225,000 polygons) derived from around 100 soil and land surveys carried out in Victoria over the past 70 years<br>TAS the List: integrated land and property information<br>MySoil summarises thousands of soils into 15 broad soil types. | SPADE:http://www.environment.nsw.gov.au/eSpade2Webapp<br>SALI:http://www.environment.nsw.gov.au/topics/land-and-soil/soil-data/salis<br>Qld_Globe: http://www.data.qld.gov.au/maps-geospatial/qld-globe<br>VSIS:https://www.data.vic.gov.au/data/dataset/victorian-soil-type-mapping<br>The List: http://dpipwe.tas.gov.au/land-tasmania/the-list | eSpade:Creative Commons Attribution 4.0 licence (CC BY 4.0)<br>Qld_Globe: Creative Commons - Attribution 3.0 Australia License<br>VSIS -Creative Commons Attribution 4.0 International | |
| Federation Uni CERDI portals e.g Online farm trials, Soil Health knowledge Base<br>(OFT, | OFT enables farm trial research to be accessed online and explored spatially via sophisticated filtering mechanisms in ways that are decision useful to agronomists and growers.<br>The OZDSM website and mapping portal provides an effective means for collaboration and testing of Digital Soil Mapping (DSM) products | https://www.farmtrials.com.au/index.php | | Txt, spreadsheet |

| | | | |
|---|---|---|---|
| OZDSM) | | | |
| 2016 SoE Land Australian Soil Classification orders | | http://data.gov.au/dataset/2016-soe-lan-soil-classification | Esri REST, shape file .shp |
| Baseline map of Australian soil organic carbon stocks and their uncertainty | | https://data.csiro.au/dap/landingpage?pid=csiro:9267 | |

## 7.2 Weather and climate data

A listing of the major datasets in the weather and climate area is given in Table 7. The BoM is Australia's premier organisation for weather and climate data. It publishes data using the CCA 3.0 licence as well as Public Access Licence (PAL) open-access licences. Where an open-access licence does not apply, or the material is to be used outside of the BoM's default terms of use, a Bureau Access Agreement needs to be obtained.

The BoM make a number of real-time forecast, warning and observation products and analysis charts freely available via the web and FTP. These include short and long-form forecasts, district forecasts, warnings, observations, agricultural bulletins, radar, satellite and UV text and graphical products. The agricultural bulletins containing a summary of agricultural type observations on a daily time scale are available in XML for each state and territory.

Local weather records are also collected by state authorities as well as by producers and agribusinesses. Affordable weather stations are available to record direct measurements such as rain, wind speed, wind direction, air temperature, relative humidity and solar radiation as well as derived measures such as dew point, heat stress index for livestock, thermal work limit and wind gust and wind vector calculations for spray and odour drift.

Some state authorities and institutions augment the BoM's stations. For example, the WA Department of Agriculture and Food manages a network of 180 automatic weather stations throughout the state to provide timely, relevant and local weather data to assist growers and regional communities make more-informed decisions. This data includes air temperature, humidity, rainfall, wind speed and wind direction, with most stations also measuring incoming solar radiation to calculate evaporation.

Also, commercial weather networks are emerging. The Discovery Ag Water and Weather Network (DAWWN) consists of a network of 68 automatic weather stations and soil moisture probes, strategically positioned across the length of the NSW cropping belt. DAWWN provides data on rainfall, air and soil temperature, wind speed and direction, solar radiation, humidity and barometric pressure.

**Table 7: Major climate and weather datasets within the register**

| Dataset | Description | URL | License | Format |
|---|---|---|---|---|
| Australian Water Availability Project (AWAP) | The aim of the Australian Water Availability Project (AWAP) is to monitor the state and trend of the terrestrial water balance of the Australian continent, using model-data fusion methods to combine both measurements and modelling. | http://www.csiro.au/awap | Restricted for research | netCDF |
| Australian Landscape Water Balance (AWRA-L) | The Australian Water Resource Assessment Landscape (AWRA-L) Model is a 0.05° (approximately 5 km) gridded daily water balance model developed by CSIRO and the Bureau of Meteorology for Water Resource assessment purposes. It simulates the flow of water through the landscape from the**rainfall** entering the grid cell through the vegetation and soil moisture stores and then out of the grid cell through **evapotranspiration**, **runoff** or **deep drainage** to the groundwater. | | Creative Commons Attribution Australia Licence | netCDF |
| SILO climate database | SILO is an enhanced climate database hosted by the Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI). SILO contains Australian climate data from 1889 (current to yesterday), in a number of ready-to-use formats, suitable for research and climate applications. In addition, SILO provides users with access toclimate | https://data.qld.gov.au/dataset/silo-climate-database | Creative Commons Attribution 3.0 | TXT |

| | | | | |
|---|---|---|---|---|
| | change projections data for 2030 and 2050 in a daily format | | | |
| Australian Digital Forecast Database (ADFD) | The Australian Digital Forecast Database (ADFD) contains official weather forecast elements produced by the Bureau of Meteorology, such as temperature, rainfall and weather types, presented in a gridded latitude and longitude based format covering the next 7 days. | http://www.bom.gov.au/weather-services/about/forecasts/australian-digital-forecast-database.shtml | | NetCDF and GRIB2 |
| ACCESS-S (BoM, available 2018) | ACCESS-S (the seasonal prediction version of ACCESS) will operate at a 60 km resolution. | http://poama.bom.gov.au/info/access-s.html | Access to registered users | NetCDF and GRIB2 |
| ACCESS-C (BoM | 4 km scale( capital cities and surrounds), Hourly | http://www.bom.gov.au/nwp/doc/access/NWPData.shtml | | NetCDF and GRIB2 |
| ACCESS-TC (BoM) | 12 km, Hourly | http://www.bom.gov.au/nwp/doc/access/NWPData.shtml | | NetCDF and GRIB2 |
| ACCESS-R (BoM) | 12 km, Hourly and 3-hourly | http://www.bom.gov.au/nwp/doc/access/NWPData.shtml | | netCDF, CF-1.4 |
| ACCESS-G (BoM) | 25 km, 3-hourly and 6-hourly | http://www.bom.gov.au/nwp/doc/access/NWPData.shtml | | |

## 7.3 RS imagery data

The Earth Observing System Data and Information System (EOSDIS) is a key core capability in NASA's Earth Science Data Systems (ESDS) Program[15]. EOSDIS data products are processed at various levels ranging from Level 0 to Level 4. Level 0 products are raw data at full instrument resolution. At higher levels, the data are converted into more useful parameters and formats. All Earth Observation System (EOS) instruments must have Level 1 products. Most have products at Levels 2 and 3, and many have products at Level 4. A common phrase used to describe the data processed to the higher levels is 'analysis ready'. An example of Level 4 or 'analysis ready' data in the register would be the GIS layer produced by the QLD Government's DSITI.[16] It reports the percentage of ground area occupied by the vertical projection of foliage. The Remote Sensing Centre foliage projection cover mapping is based on an automated

[15] earthdata.nasa.gov/earth-science-data-systems-program

[16] www.qld.gov.au/dsiti

decision-tree classification technique applied to dry season (May to October) Landsat-5 TM, Landsat-7 ETM and Landsat-8 OLI imagery for the period 1988–2013. Corrections have been applied to remove errors due to topographic effects, cloud, cloud shadow, water, cropping, and regrowth following clearing.

Imagery products available from Geosciences Australia are under the CC Licence 3.0; with some older datasets still with legacy licence agreements.

A summary of the datasets in the RS imagery area is given in Table 8.

**Table 8: Major imagery datasets within the data register**

| Dataset | Description | URL | License | Format |
|---|---|---|---|---|
| Landsat imagery Mosaic | Geoscience Australia is distributing Landsat MSS, TM and ETM+ data for 19 epochs or time frames ranging from 1972 to 2010 covering Australia. | http://www.ga.gov.au/scientific-topics/earth-obs/accessing-satellite-imagery/ordering/product-information/landsat-prices | Landsat: Creative Commons attribution 3.0 Australia (CC BY 3.0)<br>MSS:; https://earthexplorer.usgs.gov/ | GeoTIFF, CCRS |
| Broadacre: Landsat, Sentinel 1, Sentinel 2, MODIS | Water Observations from Space Fractional Cover NDVI Surface Reflectance | http://www.ga.gov.au/interactive-maps/#/theme/water/map/wofs | | |
| EOSDIS Worldview | The Worldview tool from NASA's Earth Observing System Data and Information System (EOSDIS) provides the capability to interactively browse global, full-resolution satellite imagery and then download the underlying data. | https://worldview.earthdata.nasa.gov/ | United States Government as represented by the Administrator of the National Aeronautics and Space Administration.<br>All Rights Reserved. | JPEG, PNG, GeoTIFF, and KML. |

## 7.4 Land use and property boundaries information

Data describing land use and property boundaries comes from several sources under the jurisdiction of either federal or state governments depending on the type and purpose of the data. Data can be associated with many purposes relating to topography, administrative boundaries, land use, jurisdiction, drainage, groundwater, planning, licences, permits and irrigation to list a few.

However, many of the datasets listed in the data register are created by Geoscience Australia of which approximately one half are topographic maps.

Geoscience Australia provides web services for public use that allow access to data without having to store datasets locally. Geoscience Australia supports a variety of web-service protocols, including Open Geospatial Consortium (OGC) services and ESRI mapping and image services. These services are listed on their website services.ga.gov.au.

PSMA provides an API called PSMA Cloud[17] that allows address verification and geocoding, web-feature service queries and web-map service queries and services based on enhancing this API.

A summary of the datasets in the land use and property boundaries area is given in Table 9.

**Table 9: Number of land use and property boundaries datasets from different sources within the data register**

| Dataset | Description | URL | License | Format |
|---|---|---|---|---|
| Australian Irrigation Areas (Vector), Version 1A, National Land and Water Resources Audit | This data set shows designated and actual irrigation areas in Australia compiled by the National Land Use Mapping Project of the National Land and Water Resources Audit to assist in the identification of irrigation areas in Australia. | http://data.gov.au/dataset/australian-irrigation-areas-vector-version-1a-national-land-and-water-resources-audit | Creative Commons Attribution 3.0 Australia | ESRI Shape file |
| Australian Collaborative Land Use and Management Program - | National land use data is available for the 1992-93, | http://www.agriculture.gov.au/abares/aclump/land-use/data-download | Creative Commons Attribution 3.0 Australia Licence | ESRI S Grid |

[17] www.psma.com.au/psmacloud

| | | | | |
|---|---|---|---|---|
| Dept of Ag & Water Resources - ABARES | 1993-94, 1996-97, 1998-99, 2000-01, 2001-02, 2005-06 and 2010-11 financial years mapped at the national scale (1:2,500,000) using ABS agricultural commodity data and satellite imagery | | | |
| Catchment Scale Land Use Data | This dataset is the most current national compilation of catchment scale land use data for Australia (CLUM), as at May 2016. It is a seamless raster dataset that combines land use data for all state and territory jurisdictions, compiled at a resolution of 50 metres by 50 metres. It has been compiled from vector land use datasets collected as part of state and territory mapping programs through the Australian Collaborative Land Use and Management | [http://data.gov.au/dataset/catchment-scale-land-use-of-australia-update-may-2016](http://data.gov.au/dataset/catchment-scale-land-use-of-australia-update-may-2016) | Creative Commons Attribution 3.0 Australia Licence | ESRIS GRID |

| | | | | |
|---|---|---|---|---|
| | Program (ACLUMP) | | | |
| PSMA Administrative Boundaries | | http://data.gov.au/dataset/psma-administrative-boundaries | Data Licence (PSMA Distribution Pty Limited) | ZIP, ZIP (PDF) |
| PSMA CadLite (Point) (August 2016) | Cadastre is a seamless national cadastral database of Australia's land parcels | http://data.aurin.org.au/dataset/psma-cadlite-point-na | Data Licence (PSMA Distribution Pty Limited) | HTML |
| PSMA CadLite (Polygon) (August 2016) | Cadastre is a seamless national cadastral database of Australia's land parcels | http://data.aurin.org.au/dataset/psma-cadlite-polygon-na | Data Licence (PSMA Distribution Pty Limited) | HTML |
| PSMA Hydrology (Line) (November 2012) | Spatial coverage of Australia's Transport Network, bodies of water (and | http://data.aurin.org.au/dataset/psma-hydro-line-na | Data Licence (PSMA Distribution Pty Limited) | HTML |

| | | | | |
|---|---|---|---|---|
| | islands) and 'green' spaces. • Transport is a digital representation of all roads, airports and railways within Australia. • Hydrology is a digital representation of oceans, lakes, rivers, islands and other bodies of water. • Greenspace is a digital representation of parks, reserves, recreational areas and open space. | | | |
| PSMA Land Tenure (Polygon) (August 2016) | The Land Tenure dataset is based on the Australian Cadastral Boundaries in the CadLite dataset. The Land Tenure Dataset provides a hierarchical classification of tenure with four levels. | http://data.aurin.org.au/dataset/psma-tenure-na | Data Licence (PSMA Distribution Pty Limited) | HTML |
| PSMA Localities (August 2016) | The Administrative Boundaries for Australia, an ISO 19131 compliant description, provides an optimised | http://data.aurin.org.au/dataset/psma-localities-na | Data Licence (PSMA Distribution Pty Limited) | HTML |

| | |
|---|---|
| | quality geometric description and a set of basic attributes of the Australian administrative boundaries. |
| FOUNDATION SPATIAL DATA FRAMEWORK | The Foundation Spatial Data Framework (FSDF) provides a common reference for the assembly and maintenance of Australian and New Zealand foundation level spatial data in order to serve the widest possible variety of users. It will deliver a national coverage of the best available, most current, authoritative source of foundation spatial data which is standardised and quality controlled. |

# 8 The role of decision-support tools: turning data into insight

'Decision support' is the process of improving decision making by making some combination of information and analytics[18] available to a decision maker. Most sources of rural data need to be mediated through some form of decision support if they are to benefit landholders. In order to make the information or knowledge available, a decision-support tool requires some kind of user interface; the interface is commonly implemented using ICT, but this is not a necessary feature. **Error! Reference source not found.** illustrates a typical agricultural decision-support workflow.

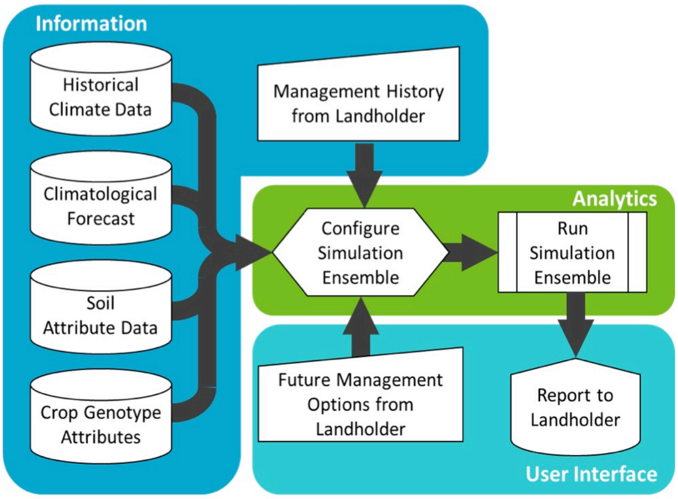



**Figure 5: Information flows in the Yield Prophet tool, showing the key components: Information, Analytics, and a User Interface**

Rural decision-support software can have a range of different purposes (the following list is slightly expanded from that provided by McCown 2002b):

- monitoring and diagnosis – some decision-support tools are designed to provide new information about the current state of plants, animals or land; the integration of this information into a decision-making process is left to the user. These tools provide value to a decision maker by allowing *current conditions* to be better understood, often by deriving a diagnostic system parameter that would otherwise be inaccessible and/or relatively costly to the decision maker. Tools provided with many spatial sensing products (e.g. yield monitor maps, mapping of canopy temperature or cover from UAV data) fall into this category.

---

[18] *Analytics* is defined as 'the systematic computational analysis of data or statistics'; in practical terms it is the process of converting information into knowledge by means of computation. The term includes a wide range of computational techniques including predictions based on statistically derived relationships, biophysical simulation or machine-learning.

- analysis of options in highly structured tasks – tools with this purpose are the most widespread agricultural applications. They contribute value to the decision-making process through the use of analytics that are powerful in estimating the *future outcomes* of alternative actions, often in conjunction with a monitoring step, and they typically focus on a small number of variables that are relevant to the task. The intended user is typically a producer or else an advisor, although these tools can also be found in regulatory contexts (Stewart 2008). Perhaps the best-known example of this 'decision calculus' tool in Australian agriculture is the Yield Prophet[19] (Birchip Cropping Group; Hochman et al. 2009), in which the user can explore the likely consequences of a number of specific crop management decisions such as cultivar choice or nitrogen fertiliser rates, based on probabilistic estimates of their consequences for crop yield.
- provision of prescriptions – tools with this purpose share the same underlying rationale and logic as those in the previous category, but differ in that they select a single recommended action. A simple example of a prescription tool (control decisions for silverleaf whitefly in cotton) is shown in **Error! Reference source not found.**. Some prescription tools, such as the FieldView[20] tool delivered by the Climate Corporation in the US, are designed to produce 'packages' of prescriptions that cover multiple decisions – and the interactions between them – simultaneously.

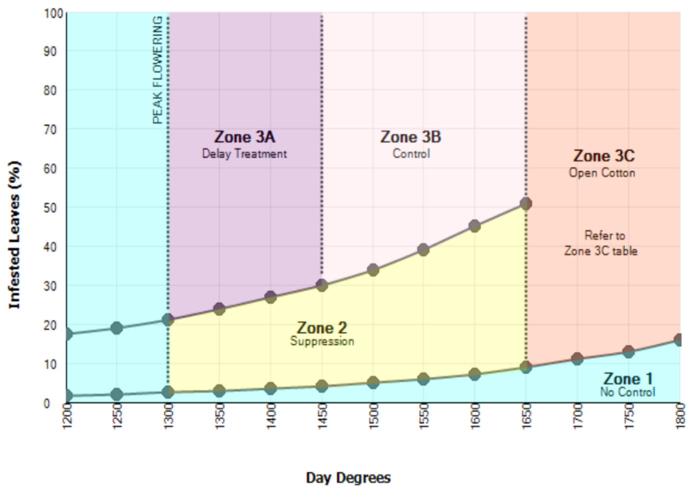



**Figure 6: A simple prescription tool: silverleaf whitefly control recommendations from CSIRO's *CottASSIST* tool**

- use in consulting – these tools are based on 'versatile simulators' (McCown 2002b), i.e. complex simulation models that are designed to mimic system function and performance cost-effectively. A problem is defined by the ultimate user (a producer, a policy maker, or some other actor), an advisor then applies the simulator to the problem and its particular circumstances. The analysis process differs from the other

[19] www.yieldprophet.com.au

[20] www.climate.com

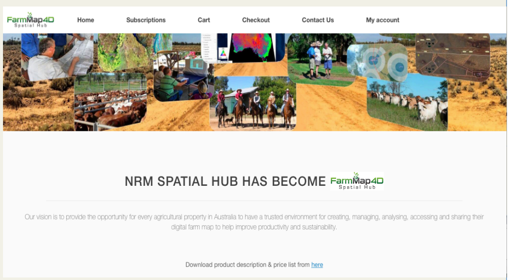
kinds of tool in that the task is typically not well structured, so that the set of possible decision options emerges from an iterative process of asking 'what-if' questions; the consultant therefore acts as the point of interface between a 'hard systems' and a 'soft systems' approach. These tools are generally designed to provide information about a wide range of potentially relevant variables. The GrassGro decision-support tool for grazing systems (Moore et al*.* 1997) was explicitly re-designed to operate in this mode (Herrmann & Zurcher 2011).

- meeting external regulatory demands – in situations where pressure is exerted by the community at large that farming be conducted within norms and standards for environmental conservation and safety, decision-support systems can be used in two ways. Documented compliance by farmers with the recommendations from a tool that embodies the current understanding of best management practice can be used to demonstrate effective self-regulation (the CottASSIST[21] tools are used in this way by the cotton industry). Alternatively, regulatory bodies can use decision-support tools to evaluate whether proposed rural activities are acceptable, for example the widespread use of the OVERSEER nutrient budgeting tool (Wheeler et al*.* 2006) by regional planning authorities in New Zealand (Freeman et al*.* 2016).

[21] www.cottassist.com.au

## 8.1 Decision support in Australian agriculture: the state of the art

### Case Study: FarmMap4D




The Natural Resource Management (NRM) Spatial Hub is a cloud based tool that provides a step change in our capacity to manage and monitor Australia's rangelands. It has the capability to map, plan, analyse and monitor properties infrastructure, land resources and ground cover to improve pastoral and natural resource management. It delivers a number of tools to pastoralists, including access to 30 years of Landsat data (fractional cover). The NRM Spatial Hub has now been made operational as FarmMap4D, which after 4 months is being used by 500 users and aims to provide the opportunity for every agricultural property in Australia to have a trusted environment for creating, managing, analysing, accessing and sharing their digital farm map to help improve productivity and sustainability. A membership based cooperative structure is under development which will operate along the lines of a Not for Profit business holding land specific data in custodianship for the farming community. See http://www.farmmap4d.com.au/

**Box 8: A case study on FarmMap4D, a online resource for improving on-farm productivity and sustainability**

A great many decision-support products have been developed for Australian rural industries, dating back to the SIRATAC system in the 1970s (Hearn et al. 2002). The 2007 Australian Farm Software Directory produced by the Queensland Department of Primary Industries identified ~75 distinct decision-support tools, excluding software primarily designed for information recording. This variety is also seen in other countries (Rose et al. 2016 located 395 tools in the UK); it reflects the diversity of rural industries and the continuing development of new data streams and technologies. Some of the tools started as management information systems to which analytics have been added; some have been developed by machinery providers to add value to monitoring information; some are extensions of research models, often resulting from projects funded by rural R&D corporations; yet others (e.g. the MLA Feed Demand Calculator[22] and the recently released AskBill[23] product for the sheep industries), while based on research tools, were initiated by RDCs or CRCs in response to a perceived industry need.

### 8.1.1 **Diverse analytic techniques**

As a result of their diverse purposes and origins, a wide range of analytic techniques are embedded within the currently available decision-support tools. Because of the uncertain

[22] mbfp.mla.com.au/Setting-directions/Tool-13-Feed-Demand-Calculator

[23] www.askbill.com.au

nature of the Australian climate, decision-support tools that forecast outcomes tend to rely on biophysical simulations of varying levels of complexity (e.g. the Yield Prophet, hydroLOGIC for cotton (Richards et al. 2008) or AskBill). At its simplest, however, the analytic process can involve the computation and presentation of a summary statistic (e.g. degree-day counts, as in the federally funded CliMate[24] app, or the NDVI). Other tools are based on straightforward algebraic calculations based on user-input data and/or tables of generic data; many examples of this type have an explicitly financial focus, for example the VegTool[25] gross margin comparator for vegetable production. There are also tools that rely on predictive equations generated from statistical analysis of experimental or other field data (e.g. the LambAlive tool (Donnelly et al. 1997)).

More recently, machine-learning techniques[26] have started to be employed to develop predictive equations for use in agricultural decision support. The most widely publicised example is the work of Climate Corporation in North America. Machine-learning techniques approaches rely on the collation of large, consistent datasets of outcomes (e.g. crop yields) that can be related to other large, consistent datasets of potential predictors; the data-management issues raised in Section 6 must therefore be resolved if they are to find widespread application in Australian agricultural production. As well as offering the potential for improved prediction of outcomes in task-analysis tools, however, machine learning offers the prospect of analytics that can update themselves as farming practices shift, through the ongoing (and automated) collection of data and re-estimation of predictive equations.

### 8.1.2 **Dissemination channels in transition**

The earliest agricultural decision-support tools in Australia were delivered by model access to mainframe computers (Hearn et al. 2002) but nearly all tools developed during the 1980s and 1990s were designed for use on a stand-alone personal computer. Spreadsheet implementations have historically been quite common; for many tool producers, the quality-assurance drawbacks of a spreadsheet were outweighed by the familiarity to users of the spreadsheet interface.

In recent years, however, a migration of agricultural decision support to the Internet has taken place. At its simplest, existing tools have been hosted on their providers' websites, thereby improving their findability and accessibility. The Yield Prophet was an early Australian example of server-based computation delivered via a webpage; the attractions of this technical approach are the ubiquity of the web browser as a channel plus cheaper and more-convenient software distribution and updating. In parallel, some long-established tools (e.g. GrazFeed[27]) have been re-implemented as apps for use on portable devices.

---

[24] grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2013/03/climate-a-smart-phone-app-for-farmers

[25] ausveg.com.au/resources/economics-statistics/gross-margin-tool/

[26] A variety of terms is used for this class of techniques, including 'deep learning' and 'predictive analytics'.

[27] http://www.hzn.com.au/grazfeed.php

Given the advantages for developers and the widespread uptake of the necessary devices, it might be expected that this shift toward app-based or web-based delivery of decision support will soon be complete. Over the medium term, however, automation of agricultural husbandry may well result in a need to decentralise the analytics for small-scale, tactical decisions onto the machinery that is carrying out the tasks; examples might include determining whether a weed is worth killing, or the automatic drafting of livestock into different paddocks. What this will mean for the overall process of decision making, and the extent to which automation can work with copies of centrally maintained algorithms versus the extent to which local machine learning will need to take place, is as yet unknown.

### 8.1.3 **Technical challenges to successful adoption of decision support in Australia**

Historically, gaining widespread adoption of decision-support tools has been a difficult task. This phenomenon – the 'problem of implementation' – is not limited to Australia (Rose et al*.* 2016) nor to agriculture (McCown 2002a). As a result, successful decision-support systems in Australia have generated significant industry benefit through relatively small user bases, often by leveraging the networks of influential actors such as agricultural advisors. For example, Yield Prophet has in recent years been applied to just under 1000 paddocks across the country. A notable exception in this respect is the CottASSIST suite of tools, which appears to have generated almost 100% uptake over a 10-year period.

The social roots of this 'problem of implementation' are the subject of other research in the *Precision to Decision* project (Zhang et al*.* 2017) and so are not covered here. Technical challenges for decision-support developers include:

- high fixed costs of development caused by diverse populations of potential users – especially with respect to their objectives in farming, the difficulties in accessing and re-using publicly held data described in Section 6, and the lack of consistent interfaces to on-farm data records
- limited context-specificity despite this being critical to landholders, caused by the coarse spatial resolution of public environmental data (especially soils and weather) compared with other OECD countries and, once again, the lack of ready links to on-farm data
- high climatic variability compared with most other developed countries, resulting in a need to communicate probabilistic information in many contexts
- need for high quality user interfaces because potential users are time-poor and because much of the useful information that decision support can provide is complicated.

## 8.2 Decision support in ag-tech: the rise of 'platforms'

The perception of commercial opportunities in digital agriculture has seen an explosion of 'platforms' looking to gain a foothold in the market. Rather than starting from computer models and interfaces designed by agricultural scientists and targeted at particular decisions, these new platforms are based on ideas and models that have been successful in other digital industries.

## Case Study: Digiscape

The *Digiscape* Future Science Platform is a CSIRO initiative that is reinventing the ways that rural decision-makers can use information and analytics. Digiscape is embracing the complexity of digital agriculture, addressing multiple dimensions simultaneously to help Australian farmers and land managers innovate faster:

- novel decision support products in six diverse application areas: grains, prawn aquaculture, N management in sugar, GHG mitigation, precision irrigation and on-farm experimentation
- a software platform, *Conflux*, that lower the costs of delivering these – and future - products
- improved land-sector information sources (climate forecasts, soils and vegetation)
- new insights into the social conditions and risks that affect the uptake of ICT in rural Australia.

**Box 9: A case study on the CSIRO initiative Digiscape**

Despite all being marketed as 'platforms', these new software tools are actually highly diverse, reflecting different views of where the opportunities (both real and perceived) lie in the rural sector. At least four broad types of platform can be seen emerging in the North American, and to a lesser extent in the Australian, rural industries:

- aggregated views of information: these tools are similar in purpose to traditional monitoring/diagnosis tools, but present a decision maker with multiple data streams (for example presenting current weather and forecasts, soil moisture and commodity prices side-by-side). These applications provide situational awareness and are analogous to the use of 'dashboards' to provide synthesised management information in government and industry. The weakness of these products is their inability to integrate information.
- mobile apps: these are based on simple, easy-to-use interfaces and are targeted at very particular problems (i.e. they are a new way of delivering analysis of options for highly structured tasks). They are often linked with other technology such as drone-mounted or in-field sensors. Examples include the NSW Drought Feed Calculator and The Yield app for irrigation in horticulture. These tools exploit the ubiquity of smartphones and the well-developed ecosystem to market and deploy apps. The major impediment to using them in Australia is broadband coverage.
- federated analysis platforms: these are based on gaining access to data from multiple enterprises and using it to learn to predict, or to benchmark, commercially important quantities such as prices of inputs, commodities, or yields. The resulting analytics can, in principle, be used for any of the purposes described above. These applications mimic the classic 'big data' model where the flow of data permits continuous improvement of the analytics. In Europe and the US, their success is critically dependent on the availability of publicly curated soils and weather information. Variants of such platforms can also provide privileged access to suppliers and markets; in these cases, the platform can mimic the CostCo business model in which membership provides access to improved buying power.

- ‘pure’ platforms: these are platforms in the narrow sense; their purpose is to provide software infrastructure through which multiple third parties can transact business, exchange data and access digital and professional services. They typically include cloud-based storage, standard data formats and access control; access is on a subscription basis. Pure platforms are powerful tools and if successful can become dominant players. There are preliminary indications that major software companies are developing pure platforms for agriculture.

We note that some applications contain elements from more than one pattern, and that a given company’s business model may evolve from one mode to another. For example, the Climate Corporation’s Fieldview product is a federated analysis platform, but Climate Corporation appears to be evolving toward delivering a pure platform.

## 8.3 What might a desirable future for decision support look like?

### Analytics and automation reinforce one another

We envisage a future where small decisions are automated, freeing decision makers to focus on the bigger picture. Platforms like UAVs and terrestrial robots can both monitor and act in response to opportunities and threats in a production system. Like self-steering vehicles in which the controlling software lies within the GPS-enabled agriculture vehicle, the algorithms that classify disease and pest risks and take corrective actions can reside on the device – a device that can communicate and interact to enable automatic responses.

### Value extracted from the full diversity of analytics

One element of a desirable future is that the new machine-learning techniques find their full expression; another is the improvement of predictions made with more-traditional simulation approaches through the use of model-data fusion techniques. In both cases, effective means are required for collating information about on-farm activities and outcomes. Barriers to market entry of new analytic approaches – in particular barriers to accessing training data – should be as low as possible, to encourage participation by firms that are new to Australia or to agriculture.

### Fixed costs of decision-support development and deployment are lowered

From the point of view of decision-support developers – regardless of the ways that their work is deployed – a desirable future includes a range of FAIR cross-sectoral data that are available on fair terms (i.e. the realisation of the data agenda described in Section 6 including ready availability of data and knowledge bases currently held by the RDCs).

In addition, it will be essential that certain widely usable *computations* be available on a FAIR basis as well: examples include ‘harness’ software for carrying out model-data fusion to estimate current conditions on a piece of land, and methods for estimating and presenting the uncertainties in a prediction of future outcomes on that piece of land.

Sustained, targeted investment in analytic capabilities for Australian agriculture/fisheries/ forestry is an essential requirement to deliver the value of cross-sectoral data. For example, updating (model-independent) information about the changing plant and animal genotypes used here is likely to be necessary: the North American business model, where the genetics and the analytics are owned by the same commercial entities, is unlikely to emerge here in the medium term. A commitment to FAIR principles on the part of analytics providers should be a minimum pre-condition for public investment.

To exploit FAIR agricultural data and analytics at least cost, we envisage that they will need to be made available as *services* that are accessed across the Internet (the 'everything as a service' approach). This will require investment by custodians in devising and implementing interfaces to the necessary services; this process is already well advanced in the soil-information space, and to some extent for RS data.

In a service-oriented environment, the process of acquiring the pieces of a software tool becomes much simpler, but assuring the quality of the software package becomes more complex. In our desirable future there will be one or more 'staging services' available to tool developers; these services will simplify handling the technical aspects of trust, especially access control (i.e. who can use this information or computation?), data quality assurance (i.e. is that sensor working reliably?) and provenance (i.e. where did these numbers come from?).

### Better and different analytics reach decision makers

If the current limitations to data access and re-use can be overcome, we see a wide range of opportunities to improve (or supersede) existing decision-support software. Table 10 provides examples of these possibilities.

**Table 10: Some possible future decision-support software in a world with improved management of rural data and analytics**

| | IMPROVEMENTS TO EXISTING TOOLS | NEW KINDS OF TOOLS |
|---|---|---|
| Monitoring and diagnosis | • Higher resolution, more-frequent, maps of crop/forage/tree using metrics that are better suited to diagnosing specific problems | • Production/financial benchmarking services that are based on wider panels of properties, take local context into account and are available closer to real time<br>• Simple crop development monitoring for diverse horticultural crops that includes medium-term forecasts |
| Analysis of options in highly structured tasks | • Forecast-based husbandry decision support (e.g. Yield Prophet or AskBill) predict with reduced uncertainties, resulting in increased confidence in decisions | • Variable-rate planning for fertiliser and water inputs that balances farmer objectives and constraints against conditions sensed at small scales<br>• 'Intelligent assistants' for one-off decisions that are based on textual knowledge-bases as well as numeric data |
| Provision of prescriptions | • Automatic feeding of dairy cows based on their day's intake as well as currently monitored attributes such as yield potential | • Entry of North American 'prescription agriculture' providers to Australia not limited by data supply |
| Use in consulting | | • Annual land use allocation decisions on cropping and mixed farms supported by provision of multiple information streams |
| Regulatory compliance | | • Access to EU markets or to price premiums supported through monitoring and interpretation of farm-scale environmental conditions |

In addition, we believe that as the fixed costs of developing decision tools fall, landholders themselves will be able to take advantage of the services we describe above to develop their own analytics tools. Examples might include being able to send crop-monitor data to a consultant without a second thought; building specific data streams or analytic modules into business-specific dashboards; using public weather and soil data when analysing on-farm experiments; or reducing the costs of carrying out on-farm experiments as part of a local collective.

# 9 An agriculture register of decision-support tools

Table 11 presents our register of common software tools for turning agricultural data into a decision. Many of these tools were identified from our engagement with farmers, producers, and industry experts. Our goal was not to identify every available software tool but only those tools of importance.

Many of the agricultural software platforms presented in Table 11 have one or more of the following components:

- Robotics: robotics represents a large component of precision agriculture. The technologies include self-steering tractors, variable-rate fertilisers and sprayers, and robots (Agbots) for weed removal, disease detection and treatment and harvesting of fruit.
- Logistics: logistics particularly in determining the supply of inputs such as chemicals and seeds as well as the scheduling of harvestings. Some of the larger software platforms are sold by input suppliers.
- Record keeping: the platforms are often built around a database management system that is housed on a web-based file server or cloud. This component takes data from a number of sources: different sensors, keyboard entry, downloads from public or private data repositories and output information via web tools, SMS messaging services, and scripts for machinery or other devices. Information can be exported to allow producers to share and compare for benchmarking or other purposes.
- Optimisation of processes: an example of process optimisation is prescriptive planting whereby yield is maximised by regulating planting and fertiliser rates depending on soil and weather conditions.
- Product tracking: the ability to track food through the production chain provides processors, retailers and consumers with information about product source and processing with respect to food safety, working conditions, sustainability or other environmental issues.
- Market analytics: market predictions based on supply and demand data allow producers to produce the type of product that maximises profit at time of harvest.
- Deterministic agricultural production systems: software tools such as APSIM and Yield Prophet are crop simulators that use the essential components of growing a crop using

soil, weather, climate data and crop type to allow farmers to make decisions around crop yields.

- Retrospective studies: producers can look at historical information from different sources to look for patterns or associations to better understand the potential drivers, factors and decisions that have impacted on their past production. Data sharing allows producers to benchmark their performances.

### Table 11: Register of major software products used by agricultural industries

When known, the use of a particular data type by a product is marked with an 'X'. The use of data may relate to a platform broadly or to a particular tool so the 'X' may appear beside the platform and not a particular module when applicable.

| COMPANY AND PRODUCT | SOILS | WEATHER | CLIMATE | IMAGERY | BOUNDARIES | OTHER MAJOR |
|---|---|---|---|---|---|---|
| **Ag Leader** | | | | | | |
| **Agfinity** | X | | | X | X | Yield |
| **Directcommand** | | | | | | |
| **Incommand** | | | | | | |
| **Intelliscope** | | | | | | |
| **Seedcommand** | | | | | | |
| **SMS** | | | | | | |
| **Yield Monitoring** | | | | | | |
| **AgData Phoenix** | | | | | | |
| **Financial (lite/financial/pro)** | | | | | | |
| **Production** | X | X | | X | X | Yield |
| **Aggateway** | | | | | | |
| **ADAPT** | | | | | | Record keeping |
| **Tools** | | | | | | |
| **AgriDigital** | X | X | | X | X | Yield, financial |
| **AgriDigital** | | | | | | |
| **Agworld** | | X | X | | | |
| **Agworld Everywhere** | | | | | | |
| **AUSVEG** | | | | | | Industry statistics |
| **VegTool Gross Margin Tool** | | | | | | Yield, price, area |
| **Back Paddock Company** | | | | | | |
| **Adviser** | | | | | | Financial record/analysis |
| **CornerPost** | | | | | | Record keeping |
| **Manager** | | | | | | |
| **Mobile** | | | | | | |
| **Reader** | X | | | | | |
| **SoilMate** | | | | | | |
| **Birchip Cropping Group** | | | | | | |
| **Yield Prophet** | X | | X | | | Yield |
| **Climate** | X | X | X | X | X | |
| **FieldView** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CRDC** | | | | | | |
| **CottAssist** | X | X | X | | | Yield |
| **Fairport** | X | X | | X | X | Yield |
| **gpMapper** | | | | | | |
| **Grape Forecaster** | | | | | | GIS layers |
| **MindMyAssets** | | | | | | On-farm map info |
| **PAM** | | | | | | On-farm grape samples |
| **PDP** | | | | | | Vehicle records |
| **PocketPAM2** | | | | | | |
| **Grapelink** | X | X | | X | X | Financial |
| **ChemCheck** | | | | | | |
| **Grapeweb** | | | | | | Spray records |
| **Grapeweb** | | | | | | |
| **GRDC** | | | | | | Spray records |
| **APVMA** | | | | | | |
| **Crop Disease Au** | | X | X | | | Factsheets |
| **Field Pea** | | | | | | |
| **GrowNotes** | | | | | | |
| **Insect ID** | | | | | | |
| **Lentils App** | | | | | | |
| **MyCrop** | | | | | | |
| **SoilMapp** | | | | | | |
| **SoilWaterApp** | | | | | | |
| **Weed ID** | | | | | | |
| **WeedSmart** | | | | | | |
| **Winter Cereal Nutrition** | | | | | | |
| **GRCD/USQ** | | | | | | |
| **Australian CliMate** | | | X | | | |
| **Horizon Agriculture** | | | | | | |
| **GrazFeed** | | X | | | | Livestock, supplementary feeds |
| **GrassGro** | X | | X | | | Livestock, prices |
| **John Deere** | | | | | | |
| **APEX** | | | | | | |
| **Connect Mobile** | X | X | | X | X | Equipment data |
| **Harvest Identification** | | | | | | |
| **Harvest Mobile** | | | | | | |
| **HarvestLab** | | | | | | |
| **JDLink** | | | | | | |
| **Mobile Data Transfer** | | | | | | |
| **Mobile Farm Manager** | | | | | | |
| **Operation Center** | | | | | | |
| **Yield Documentation** | | | | | | |
| **MLA** | | | | | | |
| **Feed Demand Calculator** | X | | X | | | Livestock (pre-computed simulations) |
| **Modular Information Systems** | | | | | | |
| **Rocket SystemBuilder** | | | | | | |
| **Rocket UniData** | | | | | | Fishing log |
| **Rocket UniVerse** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **OLSPS Marine** | | | | | | |
| **Data Logger** | | | | | | |
| **Data Manager** | | | | X | | |
| **Electronic Monitoring** | | | | | | |
| **Production Wise** | X | X | X | X | X | |
| **NDVI Satellite Imagery** | | | | | | |
| **SA Gov** | | X | X | | | |
| **aginsight** | | | | | | |
| **Sense-T** | | | | | | |
| **Pasture Predictor** | X | X | | X | | Yield |
| **Sheep CRC** | | | | | | |
| **AskBill** | | X | X | X | | |
| **SST Software** | | | | | | Fishing log |
| **SST Summit (Basic/Pro)** | | | | | | |
| **SuccorfishM2M** | | | | | | |
| **Catch App** | | | | | | |
| **SC2** | X | X | | | | Inter-row distance |
| **SC4** | | | | | | Variety performance data |
| **Syngenta and CSD – Fast Start for Cotton** | | | | | | |
| **Planting Green Light** | | | | | | |
| **Planting rate** | | | | | | |
| **Replant Calulator** | | | | | | |
| **Soil Temp Net (broken)** | | | | | | |
| **Variety Perf'nce (VP)** | X | X | | | | |
| **VP Comparison** | | | | | | |
| **The Yield** | | X | | | | |
| **Sensing+** | | | | | | Disease risk |
| **Vinehealth Australia** | | | | | | |
| **Biosecurity Assessment Tool** | X | X | X | | | Variety performance |
| **Risk Assessment Tool** | | | | | | |
| **Yield Gap Australia** | | | | | | |
| **Yield Gap map for wheat and canola** | X | X | X | X | | |

# 10 Key findings and recommendations

## 10.1 General recommendations

This project used workshops and interviews with key stakeholders to identify which datasets and decision-support tools were currently being used across different agriculture sectors and explore where future investment opportunities may exist. Based on these interviews we identified five main cross-sectoral data types that warranted further analysis. These were soils, weather, imagery, land use and property boundaries. For each of these data types we have documented the key existing datasets, discussed the trends and opportunities, and made recommendations about a desired future state.

A key finding from this study is that thinking purely in terms of data is anachronistic. While data will always be the foundation of information products, digital technologies and advanced analytics will facilitate a much broader suite of services and products. This diversity will exist across the public and private sectors. There will be variations between the business models and intellectual property restrictions associated with them. Publicly funded agencies have an institutional role to play to facilitate a sector's evolution.

A key question is what further investment in data and services needs to be made to facilitate full uptake of decision agriculture. Economic analysis by the AFI[28] has found that there is significant value to be gained by full implementation of decision agriculture ($19.1Bn) and that, averaged over sectors, 70% of this relies on publicly available or multiple datasets (Heath et al. 2017, Table 5.1). By its nature this analysis is high level and it is not possible to map this value back to particular investments. The AFI report also does not explore the public and private return on particular investments in data. However, what can be concluded from this analysis is that there is significant value to be extracted from data-driven agriculture and a high proportion of this is critically dependant on reasonable access to data.

What we have concluded from the interviews and workshops is that the lack of data and associated knowledge is a significant impediment to new digital businesses entering this market. Acquiring data can be costly and the sales and commercialisation path may be uncertain. Carrying out research to calibrate models to underpin services is expensive and is not guaranteed to produce exploitable results. Thus, the risk of these investments and the competitive opportunities for the alternate use of this capital means that companies may not invest. This barrier is potentially amplified for digital companies that have no experience in the agricultural sector, and are therefore more uncertain about the return on any investment. Thus, we conclude there is a clear case for targeted investment in foundational information, data and services to increase the pool of potential vendors in the market.

There are other arguments for public investment in this data. An inherent feature of cross-sectoral data is that there are diffuse beneficiaries from its collection. This is potentially an advantage, in the sense that there can possibly be greater returns from investment. But it can also be a disadvantage as no one sector gets sufficient value to fund an entire program. The lack of a framework for shared investment and ambiguity around relative values is a significant impediment to coordinated action.

Coordination is a significant issue. In reviewing cross-sectoral data it has become apparent how haphazard the development of data and knowledge assets has been in some cases. While the value of information and knowledge about Australia has been recognised by Indigenous people for millennia and by new Australians since settlement, there has not been a fully coordinated strategy around its prioritisation and collection. The current data and assets reflect needs, decisions and priorities that have changed over time. This is in no sense a criticism and reflects the competing demands on resources over time. But whether this is efficient going forward, as the opportunities for predictive analytics in the agricultural sector increase, is questionable. We

[28] Precision to Decision – Analysis of the Economic Benefits and Strategies for Delivery of Decision Agriculture 2017, Australian Farm Institute

thus recommend that there is a strategic plan around cross-sectoral data assets, and that the draft version of this plan come from this document. We propose the development of an agricultural data infrastructure plan, which would outline the key data assets in existence and have a strategic plan for further development. We recommend:

1. *A national agriculture data infrastructure should be developed, based on a strategic plan rather than the result of episodic and haphazard development. The plan should be a living document that identifies the needs and the pathways to achieving them, such as public, public–private, and private investment. The plan should be regularly reviewed to assess its progress and update its goals to reflect new needs, knowledge and opportunities.*

One of the initial premises of this project was that gaps in publicly available data were a significant impediment to technologies developed in the North American market spilling over into the Australian market. While our interviews and research did suggest that more publicly available data would facilitate more business opportunities there was no single example where the absence of data was the only impediment to market entry. Australian farming systems are different, in varying degrees, to their North American counterparts. Thus, there are a range of barriers to entry and to single out publicly available data as the only impediment is not sustainable. In addition, some platform providers explicitly market the provision of farm-specific data from remote sensing or collected on-farm from deployed sensors. Thus, we think the issues affecting the development of decision agriculture are more complex. Given this, we still conclude that the lack of key information and knowledge is a contributing barrier to entry. We recommend:

2. *Targeted investment to produce foundational data and models relevant to Australian systems is needed for the development of data driven decision-support systems, particularly where lack of this information is a barrier to entry. Sustained, targeted investment in analytic capabilities for Australian agriculture/fisheries/forestry is an essential requirement to deliver the value of cross-sectoral data.*

Another key finding from this project is that while the existence of data and knowledge is necessary to facilitate decision agriculture, it is not sufficient. New sensors need research and development of processing tools to manage the challenges of practical deployment and to accommodate the inherent variation and noise of the real world. For example, they potentially need to manage the integration of information from different sensors that may exhibit variation in calibration between sensors and/or acquisition events. There also needs to be research and development to transform the raw calibrated information into indices and metrics that are reliable and predictive. Finally, there may be analytics needed to produce geographically extensive predictions, with associated uncertainties that are needed for risk-based decision making. There is therefore significant work that needs to be done to develop analysis-ready data. Not doing this is a significant barrier and condemns the data to being accessible only to a small set of experts.

Given that appropriate products exist, it is still necessary that data are findable and trustworthy. Through this project we have identified that simple portals containing links to large numbers of datasets of varying quality and spatial and temporal extent are a limited resource for new participants in the digital agriculture sector. While it is essential that data is archived and online, the large body of information potentially obscures the key pieces. The data also need to be accessible in standard formats that allow reuse and integration with sector-specific information. The FAIR (findable, accessible, interoperable and reusable)[29] protocol (Wilkinson et al. 2006) is gaining international attention as a useful framework for thinking about sharing data in a way that will enable maximum use and reuse.

We make the following two recommendations:

3. *Investment is needed to fully leverage the existing data holdings. While much data relevant to digital agriculture exist, the data are often in formats that require considerable expertise in processing and analysis to deploy operationally. This is a significant barrier to use of the data. There is a clear need to go beyond simple data portals that aggregate raw information, and to develop information systems that produce 'ready to go' data which can be used directly in analysis.*

4. *RDCs should combine to advocate for FAIR (findable, accessible, interoperable and reusable) storage and dissemination of datasets that are valuable across the rural sector and that are also widely used in other industries. Examples of classes of data where RDCs should actively advocate for secure and FAIR access include: (i) satellite imagery, (especially via Geoscience Australia and particularly to ensure reliable access to the next generation of public-sector satellites such as Sentinel-1 and Sentinel-2); (ii) historical and forecast climate information; and (iii) improved monitoring of land use.*

The sharing of data between organisations and individuals is one of the key opportunities opened up by digital technologies, but it is also one of the most challenging. Shared data can be used in a variety of ways. In combination with other publicly available data it can be used to benchmark performance of activities and enterprises, such as yield. It can coordinate activities across industries to manage pests such as mice. It can be pooled with other data and analytics to derive new cross-sectoral information products such as soil moisture and weather. The ability to gain additional value from private investments occurring in data collection should not be underestimated, but neither should the current lack of infrastructure and proven business models to support this. This is an immediate priority. We recommend:

5. *A platform or platforms are needed for owners and users of agricultural data to exchange, market and value-add data for a variety of end purposes. We recommend exploring the feasibility of an industry-good platform, with appropriate business model, that could catalyse data exchange, along with appropriate protocols around use and rights of owners and users.*

Data that is of importance to the agriculture sector is often of interest more broadly. Obvious examples are weather and remote-sensing information. Broader alliances need to be formed in these cases. Where agriculture is the primary beneficiary of investment RDCs should lead these discussions. Data is often useful for monitoring the resource base and regional planning so governments should be active participants in developing cross-sectoral data. We recommend:

---

[29] http://www.ands.org.au/working-with-data/fairdata

6. *RDCs should build partnerships with other beneficiaries to leverage investments in data where possible. Where no other beneficiaries exist, there needs to be commitment to the acquisition, provision and dissemination on topic areas where the rural sector are the primary users. An example of a class of data on which RDCs should focus their investment effort is the acquisition of functionally relevant soils data, especially beyond the broadacre cropping zone.*

The final general point to note from the interviews is that while there is a general awareness of the changes that are occurring in the agricultural sector internationally, there is no consensus about what this means and what should be done to facilitate this. There is a significant knowledge gap in this area. The new opportunities being facilitated by digital technology rely on a range of skills. To participate fully, people need knowledge of digital technologies to understand opportunities. They need knowledge of agriculture to understand the true value proposition of information and services. And, they need to understand the opportunities that digital technologies will provide for business-process innovation across the sector. While there is a pool of people with some or all of these areas of expertise, that pool is not large enough to harvest the coming opportunities. There needs to be training to increase this pool of capability. We recommend:

7. *As a matter of urgency, changes to university training must be devised to ensure a future supply of agricultural data scientists. There is a foreseeable need, both in the R&D sector and in industry, for people with digital skills who also understand the agricultural sector. Evidence indicates that the Australian university system is not producing sufficient agronomists with the required skills and that current incentives to change this situation are insufficient.*

We now consider specific recommendations relating to the five data classes identified via the workshop and consultation process.

## 10.2 Data-specific recommendations

### 10.2.1 **Soils**

The soil is one of the primary focus areas for farming decisions. Knowledge of key soil characteristics is a foundation for achieving sustained production and productive capacity. However, without an adequate information base, the distribution and characteristics of soils as they impinge on farming-system decisions are neither obvious nor easy to monitor. As a consequence, better farming-system decisions require a diagnostic system both to identify the most appropriate settings for management and to monitor how soils (and the soil–plant system) are functioning. Three important components of the diagnostic system are:

- an understanding of how soils vary across the paddock, farm and in the context of the broader landscape (e.g. expressed in digital maps of soil properties and functional types)
- an ability to detect and interpret soil changes with time (e.g. availability of nutrients, pH, organic carbon, plant-available water)
- a capacity to forecast the likely state of soils and impact on the production system under the available land management options and experienced weather and climates (e.g. through the use of simulation models).

An effective soil-information system would provide the relevant information (function, scale, timeliness) to increase agricultural efficiency, reduce risk and raise productivity.

We recommend:

8. *An Australian Soil Information Facility based on new business models to support the on-going collection, sharing and value-adding to soil information across state agencies, CSIRO, universities, and agribusiness should be established. The quality and density of digital soil information that can be readily used by public and private-sector players is limiting the development of digital agriculture products and services. While great strides have been made in the development of the Soil and Landscape Grid of Australia and the Australian Soil Information System, the data assets available are still limiting to innovation. We also recommend the complementary development of a private soil data community that incentivises and rewards the collection, use and improvement of soil data held in private hands (e.g. data from farmers' soil tests result, fertiliser companies, geophysical surveys collected by agronomists). Both these initiatives will build towards the continual improvement and subsequent dissemination of fine-scale soil products like the Soil and Landscape Grid of Australia.*

### 10.2.2 **Weather**

Better weather and climate forecasts are crucial to gaining the full benefits of data-driven agriculture. Rainfall is often the primary driver of yield and therefore accurate information at the paddock scale will significantly improve the ability to explain yield variation and apply appropriate management actions. The ability to seasonally forecast more precisely would also have profound impacts on Australian farmers' ability to risk manage the risks of Australia's highly variable climate.

There are three opportunities to improve Australian weather data. One is to find ways of harnessing the private investment in sensors. Increasingly farmers, either individually or via advisors and platforms, will invest in sensors such as weather stations or soil moisture probes as part of digital agriculture solutions. There is a significant opportunity to leverage this investment to develop better weather products. The second opportunity is to develop products that are 'ready to go' in the sense that they are tailored directly to agricultural applications and can be seamlessly incorporated into decision-support systems. The third opportunity is to improve the skill of weather and climate forecasts to enhance our resilience in agriculture. Key actions where the most impact could likely be realised are:

i. improved measurements, assessments and predictions of extreme events such as drought, heatwaves, hail or frost
ii. increased understanding of the climate thresholds and tolerances of our vulnerable commodities (e.g. heat stress in dairy cattle; wheat yields under increasing temperature and decreasing rain; humidity/rainfall near picking times for fruit and vegetables)
iii. increased skill in multi-week forecasts (10 days to 1 month) and an exploration of who can best use them, along with an integration of these forecasts into the existing decision-tool space
iv. forecasts of climate at time horizons of 6–24 months for strategic on-farm decisions such as stocking rates and investments.

We therefore make the following recommendations.

9. *A seamless mechanism is needed to draw upon the vast array of sensors and informally collected weather data to develop locally relevant forecasts and observations. The scale mismatch between climate and weather model forecasts and the required paddock-scale knowledge is an ongoing challenge. Even with increasing resolution in models, we need to focus on techniques to calibrate the forecasts with on-farm meteorological records to truly gain the value of the forecasts at the individual-paddock scale.*

10. *Agricultural organisations should explore opportunities to work with the BoM and other data providers to 'translate' weather and climate information into bespoke products with more context-relevant terms for end users. Weather and climate information (short-term and long-term outlooks) is often communicated to the farming and advisory communities in meteorological terms, but not in practical, actionable ways that directly relate to individual on-farm decision making.*

11. *There should be an investigation to identify domains that could use sub-seasonal forecasts to alter their decision-making processes and find ways to implement this data into existing decision-support tools. Sub-seasonal climate forecasts (1 week to 1 month) are an emerging product in the meteorological arena. Their potential benefits have not yet been realised in decision-support tools.*

### 10.2.3 **Remotely sensed imagery**

RS information products have the capacity to generate geographically extensive and cost-effective data and will be crucial to the full implementation of digital agriculture. There are also significant developments in sensors and platforms that will create significant new data streams. History shows that significant investment needs to occur to convert this opportunity to information products and services that can be used reliably and extensively across agricultural industries.

Investment into this information ecosystem will be a critical step into the future. This means research into, in particular:

- the evaluation of new sensing systems, the information they may provide, and the value that they offer to the agricultural industry
- reception, storage and workflows of the data such that near-real time and predictive capacity can be utilised (timeliness of results)
- how to optimise the integration/assimilation of multiple RS data streams, and how to optimise the integration/assimilation of these with proximal sensors, sensor networks, personal technology, and data analytics
- the predictive modelling capacity that is built around the information ecosystem.

We therefore recommend:

12. *Revamping how publicly available imagery is made available should be considered. RS imagery has been and will be increasingly used in digital agriculture applications. However, RS imagery that is appropriately processed and timely is not easily accessible and interpretable to those wishing to use it for digital applications. Moreover, the coverage, frequency, access to and ease of use of the emerging satellite layers (e.g.*

*Sentinel) need to be assessed and industry-wide platforms created for these layers, and integrations of them to be accessed and used. There is also a need to develop optimal metrics for prediction in Australian systems.*

### 10.2.4 **Land use data**

Land use data is useful for a wide range of purposes. It can support industry biosecurity planning, surveillance and response. It can provide better industry planning, development of infrastructure and targeting of third-party products and services. It can allow better regional planning and policies by government. If it is collected in real time it can support better crop forecasting and industry logistics.

There are significant opportunities to improve land use information. New streams of digital data from satellites, administrative sources and agriculture platforms can potentially provide a much richer information base that can be assimilated to produce more accurate and timely products. We recommend:

13. *The existing ACLUMP partnership should be leveraged with new data streams from remote sensing, government and industry to develop more timely and accurate products with multiple end uses. Improved land use data have a wide range of potential uses such as biosecurity management and industry planning. There are significant opportunities to improve on existing products to make them more timely and accurate by using new remote sensing, administrative and industry data streams and analytics.*

### 10.2.5 **Property boundaries**

Legal property boundary information is a core government function and is already well developed and has strong legislative requirements.

There is no register linking parcels, properties and legal ownership. This could be useful to automatically integrate remote monitoring to properties, and allow better understanding of industry structure. We note that information about physical property boundaries will increasingly be collected as part of digital agriculture. The value in sharing this information is still to be determined.

# 11 References


ABARES (2011) Guidelines for land use mapping in Australia: principles, procedures and definitions, 4th edition. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://data.daff.gov.au/anrdl/metadata_files/pe_abares99001806.xml.

ABARES (2015a) Addendum to the Guidelines for land use mapping in Australia: principles, procedures and definitions, 4th edition. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://data.daff.gov.au/anrdl/metadata_files/pe_agluma9abll20150415_11a.xml.

ABARES (2015b) Land use information for Australia. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://data.daff.gov.au/anrdl/metadata_files/pb_luifad9abll20151120.xml.

ABARES (2016) The Australian land use and management classification version 8. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://data.daff.gov.au/anrdl/metadata_files/pe_alumc9aal20161017.xml.

ABS (2015) National agricultural statistics review – final report (cat no. 7105.0.55.004). Australian Bureau of Statistics, Canberra. http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7105.0.55.0042015?OpenDocument.

Angus, JF (2001) Nitrogen supply and demand in Australian agriculture. *Animal Production Science* **41**, 277–288.

Arrouays, D, Marchant, BP, Saby, NPA, Meersmans, J, Orton, TG, Martin, MP, Bellamy, PH, Lark, RM, Kibblewhite, M (2012). Generic Issues on Broad-Scale Soil Monitoring Schemes: A Review, *Pedosphere*, **22**, 4, 456-469.

Arrouays D, Grundy M, Hartemink AE, Hempel JW, Heuvelink GBM, Hong SY, Lagacherie P, Lelyk G, McBratney AB, McKenzie NJ, Mendonca-Santos MDL, Minasny B, Montanarella L, Odeh IOA, Sanchez PA, Thompson JA, Zhang GL (2014) GlobalSoilMap: toward a fine-resolution global grid of soil properties. Advances in Agronomy **125**, 93–134.

Baldock J, Macdonald L, Sanderman J (2013) Foreword. Soil Research **51**, i.

Bolton GC (1981) Spoils and spoilers: Australians make their environment 1788–1980. Allen & Unwin.

Campbell A (2008) Managing Australia's soils: a policy discussion paper. Prepared for the National Committee on Soil and Terrain (NCST) through the Natural Resource Management Ministerial Council (NRMMC). http://www.clw.csiro.au/aclep/documents/Soil-Discussion-Paper.pdf.

Donnelly JR, Moore AD, Freer M (1997) GRAZPLAN: decision support systems for Australian grazing enterprises. I. Overview of the GRAZPLAN project, and a description of the MetAccess and LambAlive DSS. Agricultural Systems **54**, 57–76.

Freeman M, Robson M, Lilburne L, McCallum-Clark M, Cooke A, McNae D (2016) Using OVERSEER in regulation – technical resources and guidance for the appropriate and consistent use of OVERSEER by regional councils, August 2016. Report prepared by Freeman Environmental Ltd for the OVERSEER Guidance Project Board. www.overseer.org.nz.

Grundy MJ, Rossel RV, Searle RD, Wilson PL, Chen C, Gregory LJ (2015) Soil and landscape grid of Australia. Soil Research **53**, 835–844.

Hearn AB, Bange MP (2002) SIRATAC and CottonLOGIC: persevering with DSSs in the Australian cotton industry. Agricultural Systems **74**, 27–56.

Herrmann NI, Zurcher EJ (2011) Designing decision support systems for factorial analyses, In '19th International Congress on Modelling and Simulation. Perth, Australia', 12–16 December 2011, (Eds F Chan, D Marinova, RS Anderssen), 1209–1215.

Hicks W, Rossel RV, Tuomi S (2015) Developing the Australian mid-infrared spectroscopic database using data from the Australian Soil Resource Information System. Soil Research **53**, 922–931.

Hochman Z, van Rees H, Carberry PS, Hunt JR, McCown RL, Gartmann A, Holzworth D, van Rees S, Dalgliesh NP, Long W, Peake AS, Poulton PL, McClelland T (2009) Re-inventing model-based decision support with Australian dryland farmers. 4. Yield Prophet® helps farmers monitor and manage crops in a variable climate. Crop & Pasture Science **60**, 1057–1070.

ITPS (2015a) Status of the world's soil resources (SWSR) – technical summary, Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. http://www.fao.org/3/a-i5126e.pdf.

ITPS (2015b) Regional assessment of soil change in the southwest Pacific, Chapter 15 in 'Status of the world's soil resources – main report', Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Keogh M, Henry M (2016) The implications of digital agriculture and big data for Australian agriculture. Research Report, Australian Farm Institute, Sydney, Australia.

McBratney, AB, Mendonça Santos ML , Minasny, B (2003). On digital soil mapping, *Geoderma*, **117**, 1–2, 3-52

McCown RL (2002a) Locating agricultural decision support systems in the troubled past and socio-technical complexity of 'models for management'. Agricultural Systems **74**, 11–25.

McCown RL (2002b) Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agricultural Systems **74**, 179–220.

McKenzie NJ, Isbell RF, Jacquier DW, Brown KL (2004) Australian soils and landscapes: an illustrated compendium. CSIRO Publishing, Melbourne.

McKenzie NJ, Hairsine PB, Gregory LJ, Austin J, Baldock J, Webb M, Mewett J, Cresswell HP, Welti N, Thomas M (2017) Priorities for improving soil condition across Australia's agricultural landscapes. Report prepared for the Australian Government Department of Agriculture and Water Resources. CSIRO Agriculture and Food, Canberra.

McTainsh G, Boughton WC (1993) Land degradation processes in Australia. Longman Cheshire.

Moore AD, Donnelly JR, Freer M (1997) GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels, and the GrassGro DSS. Agricultural Systems **55**, 535–582.

NCST (2013) Establishing the Australian Soil Assessment Program. A report prepared by the National Committee on Soil and Terrain for the Soil Research Development and Extension Reference Group, 22 March 2013. https://soilstrategy.net.au/wp-content/uploads/Australian-Soil-Assessment-Program-FINAL-August-2013.pdf.

Perrett E, Heath R, Laurie A, Darragh L (2017) Precision to decision - analysis of the economic benefit and strategies for delivery of decision agriculture – draft final report. Australian Farm Institute, Sydney, August.

Rawlins, BG, Marchant, B, Stevenson, S, Wilmer, W (2017). Are data collected to support farm management suitable for monitoring soil indicators at the national scale?. *Eur J Soil Sci*, **68**: 235–248.

Richards QD, Bange MP, Johnston SB (2008) HydroLOGIC: an irrigation management system for Australian cotton. Agricultural Systems **98**, 40–49.

Rose DC, Sutherland WJ, Parker C, Lobley M, Winter M, Morris C, Twining S, Ffoulkes C, Amano T, Dicks LV (2016) Decision support tools for agriculture: towards effective design and delivery. Agricultural Systems **149**, 165–174.

Simmons AJ, Hollingsworth A (2006) Some aspects of the improvement in skill of numerical weather prediction. Quarterly Journal of the Royal Meteorological Society **128**, 647–677.

Stewart J (2008) A decision support system for setting legal minimum lengths of fish. Fisheries Management and Ecology **15**, 291–301.

SOE (2011) Australia state of the environment 2011: an independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. (Hatton TJ, Cork S, Harper P, Joy R, Kanowski P, MacKay R, McKenzie NJ, Ward T, Wienecke B) DSEWPC, Canberra.

Wheeler DM, Ledgard SF, Monaghan RM, McDowell R, de Klein CAM (2006) Overseer® nutrient budget model — what it is, what it does. In 'Implementing sustainable nutrient management strategies in agriculture' Fertilizer and Lime Research Centre Occasional Report no. 19 (Eds LD Currie, JA Hanly), 231–236, Massey University, Palmerston North.

Wilkinson MD, Dumontier M, Aalbersberg IJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten J-W, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, Hoen PAC't, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B (2016) The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data **3**, 160018.

Zhang A, Baker I, Jakku E, Llewellyn R (2017) 'Accelerating precision agriculture to decision agriculture: the needs and drivers for the present and future of digital agriculture in Australia. A cross-industry producer survey for the Rural R&D for Profit 'Precision to Decision' (P2D) project'. CSIRO, Brisbane.

# Appendices

## A.1 Workshops: how they were run and findings

Eight workshops were held in various regional locations in Australia. Participants included producers and agri-services and industry representatives. Potential participants were identified through communications through the RDCs, contacting peak producer groups and personal networks. The workshops were held over the course of four hours and were facilitated by two facilitators supported by seven to eight members of the research team. Numbers of participants at the individual workshops ranged from 12 to 25.

For the workshops, a set of questions was constructed to determine the more important decisions producers make in their enterprises and the sources and tools that were used to support these decisions. To determine the perceived gaps in producer needs, participants were asked what information and/or support tools they thought were missing. The participants were placed into one of 4 small groups to facilitate open contribution to the data-gathering exercise.

After completing the first four workshops, the process was altered to a more 'global café' approach where members of the research team lead groups of attendees through the same questions. The change in format was necessitated by the low numbers of producers compared to agri-services and industry representatives, and the concern that producers were reluctant to raise certain issues.

The schedule of workshops along with their main industry focus is shown in Table 12.

**Table 12: Location, date and main focus of workshops to identify datasets and decision-support tool use in agriculture**

| WORKSHOP | LOCATION | DATE | FOCUS INDUSTRIES |
|---|---|---|---|
| **1 (pilot)** | Gatton, QLD | 5 Dec 2016 | Horticulture/vegetables |
| **2** | Townsville, QLD | 1 Mar 2017 | Horticulture, sugar, plus other industries |
| **3** | Tamworth, NSW | 2 Mar 2017 | Meat, grains, cotton |
| **4** | Northam, WA | 16 Mar 2017 | Grains, wool |
| **5** | Wagga Wagga, NSW | 28 Mar 2017 | Pork, grains, rice |
| **6** | Tatura, VIC | 29 Mar 2017 | Dairy, plus other industries |
| **7** | Launceston, TAS | 30 Mar 2017 | Forestry, plus other industries |
| **8** | Tanunda, SA | 27 Apr 2017 | Grapes and wine |

### A.1.1 Summary of issues raised

Table 13 presents a summary of the major topics raised across the eight workshops.

**Table 13: Summary of major topics raised across the eight workshops**

| TOPIC | TOPIC |
|---|---|
| **Data literacy (entry to interpretation)** | **Soil data needs to be at finer scale** |

| | |
|---|---|
| **Reluctant or opposed to sharing of data** | **Weather data needs to be at finer scale** |
| **Lack of data integration** | **Data quality/accuracy** |
| **Datasets not fully utilised** | **Storage and security of data** |
| **Low adoption of sensor technology/precision agriculture tools** | **Software no integrated (interoperability)** |
| **Lack of predictive tools** | **Soil testing too slow** |
| **Interest in economic value of data** | **Lack of trust in data** |
| **Sensors used extensively** | **Farm management tools useful** |
| **Need for industry expert** | **Willing to share some data** |
| **Precision ag equipment use is commonplace** | **Need for crop disease forecast tool** |
| **Real time data for smaller areas/individual animals** | **Questions around value of some technologies (e.g. VRF)** |
| **Traceability is increasingly important and relies on good data systems** | **Lack of skilled labour and flexibility in employment** |
| **Need for better water allocation information** | **Too much paper-based data entry systems** |

VRF = variable-rate fertiliser

### A.1.2 Consistent issues

- The major decisions for cropping industries were to do with predicted weather and climate, soil moisture status, soil nutritional status, and pest and disease status.
- Both producers and agri-service providers voiced concerns about the accuracy of sensor technologies; in particular, for soil moisture sensors and biomass/yield sensors on harvesters. Calibration of sensors is rarely performed.
- The willingness to share data among other producers varied with the industry. Agronomists and agri-specialists would/could combine data from clients to provide feedback to producers.
- Producers, particularly large producers, are heavily reliant on expert advisors to make decisions across a range of aspects of their business.
- There are multiple digital agriculture platforms in the market with no consistent platform emerging. Data format conversion tools exist depending on the platform.
- Many data-entry systems for various platforms and regulatory tools used by producers rely heavily on manual entry, which is a major impediment to information use and quality. This agrees with our review of the how-to descriptions from a sample of applications.
- Producers raised the need for weather and climate information at paddock scale for forecast periods appropriate to planning and growth periods. This scale may be from years for forestry and tree crops down to hours for livestock and other crops. This was echoed by industry experts and interviews with producers.
- Producers raised the need for historical and current soil-property information at crop scale. The soil experts would support this and initiatives for a national collection of soil survey data have been proposed.
- Producers raised the need for soil moisture and physical-chemical data at a finer spatial scale.

- Concerns were raised about how varietal performance translates to specific soil and climate conditions. The varietal performance information is well researched (e.g. GRDC NVT[30] information and SRA's QCANESelect[31]) which provides accurate comparative information for different varieties across a range of environments. The issue seems to be in establishing which environment is applicable to an upcoming season for a grower. When any benefit of genotype expression is marginal compared to the impact of nutrition, available soil moisture and weather events such as heat stress, the worth of the information provided by these initiatives may be decreased. To reduce the producer's risk, they may choose the varieties that perform best across a range of environments. However, the criteria used by growers to choose varieties is multi-factorial and the risk associated with various options needs to consider the physical, social, and financial environment.
- There seems to be a lack of available skills in geographic information system (GIS) and agronomy/husbandry.

### A.1.3 Divergent issues

- Rural research and development corporations (RDCs) provide a lot of tools. Noticeable at workshops was the minimal mention of these tools made by producers. Many of these tools are aimed at researchers or highly skilled specialists and consultants.
- During the workshop at Northam, WA, participants raised the usefulness of land use information. Participants at other workshops did not raise this topic.
- In the fishing industries, much of the data collected is directed at managing the fisheries for sustainability.
- The willingness to share data varied among workshops and among participants within some workshops. Sometimes the differences were around the types of data being shared (geophysical versus financial) while in some situations reluctance to share data was due to maintaining a competitive advantage.

### A.1.4 Key datasets that are not currently available

- Fine spatial and temporal data of moisture and physical and chemical properties of soils
- Fine spatial and temporal data for weather information. However, as weather stations become cheaper with greater connectivity, producers are placing more weather-recording instruments on their properties.

---

[30] Grains Research and Development Corporation, 'National Variety Trials', Grains Research and Development Corporation, accessed 19 June 2017, https://grdc.com.au/research/trials,-programs-and-initiatives/national-variety-trials.

[31] 'Varieties', Sugar Research Australia, accessed 19 June 2017, https://sugarresearch.com.au/growers-and-millers/varieties/.

# 12 Glossary

| Acronym | Description |
|---|---|
| 3D | Three dimensional |
| ABARES | Australian Bureau of Agricultural and Resource Economics and Sciences |
| ABS | Australian Bureau of Statistics |
| ACCESS | Australian Community Climate and Earth-System Simulator |
| ACCESS-C | ACCESS City |
| ACCESS-G | ACCESS Global |
| ACCESS-R | ACCESS Regional |
| ACLEP | Australian Collaborative Land Evaluation Program |
| ACLUMP | Australian Collaborative Land Use and Management Program |
| ACRES | Australian Centre for Remote Sensing |
| ACT | Australian Capital Territory |
| AFI | Australian Farm Institute |
| ALA | Atlas of Living Australia |
| ALUM | Australian Land Use and Management |
| ANDS | Australian National Data Service |
| API | Application Program Interface |
| APSIM | Agricultural Production Systems sIMulator |
| ARC | Australian Research Council |
| ARM | Agricultural Risk Management |
| ASIF | Australian national Soil Information Facility |
| ASN | Australian Soil Network |
| ASRIS | Australian Soil Resource Information System |
| AURIN | Australian Urban Research Infrastructure |
| BASE | Biome of Australian Soil Environment |
| BoM | Bureau of Meteorology |
| CC | Creative Commons |
| CCA | Creative Commons Attribution |
| CLU | Common Land Unit |
| CRC | Cooperative Research Centres |
| CRDC | Cotton Research and Development Corporation |
| CRL | Community Readiness Level |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |

| | |
|---|---|
| DAF | Department of Agriculture and Fisheries |
| DAP | Data Access Portal |
| DAWWN | Discovery Ag Water and Weather Network |
| DEM | Digital Elevation Model |
| DPE | Department of Planning and Environment (NSW) |
| DSITI | Department of Science, Information Technology and Innovation (QLD) |
| ENSO | El Niño–Southern Oscillation |
| EOS | Earth Observation System |
| EPA | Environment Protection Authority (Victoria) |
| FAIR | Findable, accessible, interoperable and reusable |
| FORAGE | Framework for Online Report Generation |
| FTP | File Transfer Protocol |
| GA | Geosciences Australia |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GRDC | Grains Research and Development Corporation |
| GSP | Global Soil Partnership |
| ICT | Information and Communications Technology |
| IMOS | Integrated Marine Observing System |
| IOD | Indian Ocean Dipole |
| IRL | Investment Readiness Level |
| KN | Knowledge Network |
| LIDAR | Light Detection And Ranging |
| MCV | Managing Climate Variability program |
| MLA | Meat & Livestock Australia |
| NCI | National Computational Infrastructure |
| NSW | New South Wales |
| NVT | National Variety Trials |
| OEH | Office of Environment and Heritage (NSW) |
| PAL | Public Access Licence |
| POAMA-2 | Predictive Ocean Atmosphere Model for Australia |
| PSMA | PSMA Australia Limited |
| QLD | Queensland |
| R&D | Research and Development |
| RDC | Rural Development Corporation |
| RIRDC | Rural Industries Research and Development Corporation |

| | |
|---|---|
| SA | South Australia |
| SDG | Sustainable Development Goal |
| SEED | Sharing and Enabling Environmental Data |
| SILO | Scientific Information for Land Owners |
| SOI | Southern Oscillation Index |
| SRA | Sugar Research Corporation |
| SST | Sea Surface Temperatures |
| TERN | Terrestrial Ecosystem Research Network |
| TRL | Technology Readiness Level |
| UAV | Unmanned Aerial Vehicle |
| UK | United Kingdom |
| UNE | University of New England |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UQ | University of Queensland |
| URL | Uniform Resource Locator |
| US | United States of America |
| USC | University of Sunshine Coast |
| USDA | US Department of Agriculture |
| USGS | United States Geological Survey |
| VIC | Victoria |
| WA | Western Australia |
| WNSW | Water New South Wales |
| XML | eXtensible Markup Language |
| YPL | Yield Prophet Lite |

CONTACT US

**t** 1300 363 400
+61 3 9545 2176
**e** csiroenquiries@csiro.au
**w** www.csiro.au

AT CSIRO, WE DO THE EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today – for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australia's catalyst for innovation.

CSIRO. WE IMAGINE. WE COLLABORATE. WE INNOVATE.

FOR FURTHER INFORMATION

**Data61**
Ross Darnell
**t** +61 7 3833 5534
**e** ross.darnell@data61.csiro.au
**w** www.csiro.au/data61

**Data61**
Simon Barry
**t** +61 0 0000 0000
**e** simon.barry@data61.csiro.au
**w** www.csiro.au/data61

ACCELERATING PRECISION AGRICULTURE TO DECISION AGRICULTURE - P2D PROJECT RESEARCH PARTNERS

PROJECT LED BY

Australian Government

Cotton Research and Development Corporation