
# Farmers' use of weather & forecast information in the Western Australian wheatbelt

Report to the Bureau of Meteorology

Myrtille Lacoste

Marit Kragt

THE UNIVERSITY OF WESTERN AUSTRALIA
School of Agriculture and Environment

2018

Department of Agriculture and Food
GOVERNMENT OF WESTERN AUSTRALIA

Australian Government
Bureau of Meteorology

ROYALTIES FOR REGIONS

This work was funded by the Bureau of Meteorology (BoM) of the Australian Government through the Royalties for Regions program of Western Australia, as part of a larger project to estimate the benefits of Doppler radar investments in the Western Australian wheatbelt. This work was conducted at the University of Western Australia (UWA), School of Agriculture and Environment, Department of Agricultural and Resource Economics, under the supervision of Dr Marit Kragt.

For more information:

| | | |
|---|---|---|
| UWA project investigator | Dr Myrtille Lacoste | myrtille.lacoste.ag@gmail.com |
| UWA project supervisor | Dr Marit Kragt | marit.kragt@uwa.edu.au |
| BoM regional director WA | Mike Bergin | mike.bergin@bom.gov.au |

The author thanks all the farmers who contributed their time to this study, as well as the six industry experts consulted for their advice and three anonymous reviewers for their comments.

This report can be cited as:

Lacoste M. & Kragt M. (2018) Farmers' use of weather and forecast information in the Western Australian wheatbelt. Report to the Bureau of Meteorology. Department of Agricultural and Resource Economics, The University of Western Australia: Perth.

## *Executive summary & recommendations*

Evaluating the economic benefits from investments in weather and forecast information is hindered by a lack of knowledge about how broadacre farmers use this information. It remains unclear which weather and forecast products farmers use, and which features are considered most important. Little is also known about how the available weather and forecast information impacts the management decisions of farmers, for instance how different forecast horizons impact farming practices along the year.

This study is the first to address these gaps. Primary data from 51 farmers was collected using detailed interviews in 3 locations of the Western Australian wheatbelt between July and October 2017.

Major results and *recommendations* included:

- The majority of farmers interviewed **expressed great confidence in the competence of the Bureau of Meteorology (BoM) and considered that, overall, forecasts skills have greatly improved along the years**. Confidence in forecast was very high for forecasts up to 4 days. A large proportion of farmers acknowledged the difficulties of achieving reliable predictions at longer horizons.
  - → *BoM should continue current activities. Levels of trust are high, demonstrating the overall adequacy and broad scale relevance of BoM activities and outputs to the broadacre industry.*

- Most farmers accessed **multiple weather and forecast products; half provided by BoM, half by third-parties.** The main eight products, representing 70% of all main sources of information mentioned, were: BoM's radar, Elders' app, BoM's 1 to 7-day forecasts, WillyWeather, Weather Zone, BoM's MetEye, OCF via AWN, and BoM's 4-day agricultural forecasts. Farmers' choices were justified by **ease-of-use, performance, requirements for specific features, and the need to build an 'overall picture' by comparing several perspectives**.
  - → *If one of BoM's objectives is to improve the delivery of information, there is scope for improvement. Some key products such as MetEye are trusted and comprehensive, but cumbersome. Generally, the differences and overlaps among the myriad of products offered by BoM are unclear.*

- → *The BoM website is well used, however the smartphone app market is almost entirely dominated by third-parties. To compete, BoM strategic directions regarding the development of products must take into account the successful features of third-party products, notably with regards to platform format (e.g. concise, convenient, interactive) and market positioning (e.g. niche features such as wind mapping). Promising avenues to increase the market share among farmers also include developing apps with an easily customisable dashboard to monitor current observations (e.g. for spraying), and radar integration with other services such as cadastral maps, farm grain flows, or planning software.*
- → *Another opportunity for BoM would be to develop a product comparing the historical and local performances of various forecast products, highlighting differences in data sources and model providers.*

• **Lack of awareness limited the use of many products**, most notably those produced by BoM and DPIRD for extension and decision support purposes.

- → *A large proportion of farmers are not aware of flagship products such as MetEye, radar rainfields or weather-related decision tools which should be more clearly promoted.*
- → *The myriad of products provided on the BoM website could be re-organised, perhaps adding a "product map", and keeping in mind that MetEye does not currently represent a central 'go-to' platform for most farmers.*
- → *Farmers would benefit from workshops summarising and explaining all types of weather and forecast products available (including third-parties and their differences with BoM products). Such workshops would also represent the opportunity for BoM to gather further feedback on desirable product features. However, outreach activities must consider that farmers are time-poor, which explains the success of meteorological weather segments (on-the-go in tractors) versus time-requiring presentations - both in-person or online.*

• Farmers' overall access to weather and forecast information **was not explained** by their age, technological level, farm size, mobile coverage or location. Farmers who were younger, used more up-to-date technologies, or whom benefited from better mobile coverage were not accessing weather and forecast information more than others. This suggests that farmers' need for weather and forecast information is such that is overrides many other factors (such as personal preferences or the farm technological level).

- → *There is no need to accommodate products or target activities toward a particular segment of the agricultural population.*

• **Generally, farmers had greater confidence in short-range forecasts, which impacted their practices more than long-term forecasts.** The shorter the predicted forecast horizon, the more confidence farmers have in its reliability and accuracy, and the more that forecast influences their decisions. **The practices most impacted by weather conditions and forecasts** were general planning, spraying and sheep management; the least was harvesting. Impacts on seeding and fertiliser application varied greatly, with distinct farmer profiles identified (notably, one group relied heavily on forecasts while another disregarded all related information).

→ *Studies investigating the impacts of improved forecasts on farmers' decisions must take into account this heterogeneity, as well as realistic scopes for improvement, or risk over-estimating potential benefits. Weather and forecast information is critical to farming overall; however, differences exist, between practices and within the farming population. For instance, avoidable harvest weather-related losses could be reduced by improved 2-3 week forecasts but are low anyway; spraying and sheep management are currently near optimum; forecasts at seeding time have limited relevance for two-thirds of cropping programs (pre-decided early seeding or waiting for sufficient rainfall); pragmatic farm constraints override some forecast benefits for a proportion of the farming population (fertilising logistics, harvest labour shortage, machinery capacity at seeding).*

The weather and forecast information generated by the Bureau of Meteorology are well-regarded and extremely useful to broadacre farmers in the wheatbelt. Access to this information, directly via BoM or third-party products, is an essential component of the organisation and functioning of current farming systems. Nevertheless, in addition to enhancing the accuracy and reliability of long-term forecasts, there is scope for improvements in terms of delivery (products format, accessibility, awareness).

Monitoring weather conditions and assessing forecasts impacts on most farmers' decisions. The (perceived) performance of the forecasts varies with forecast horizons, which influences the relative importance placed on these forecasts by farmers. Currently, shorter-term forecasts (under a few days) are largely sufficient for spraying and sheep management. However, for harvesting decisions, farmers would need improved 2-3 week forecasts. Impacts on seeding and fertilising also require medium as well as long-term forecast horizons and are more complex. They vary across the farming population, with other factors such as pragmatic farm constraints overriding the role of weather forecasts in many instances.

# 1. Introduction

## An enduring lack of information about the influence of weather and forecast information on farmers' practices

## Current knowledge and challenges regarding the use of weather and forecast information by farmers

Providing weather and forecast information to the community is the object of much investment and effort, most of which is carried out by the government through the research and development of meteorological models, technologies, and outreach activities. In Western Australia, a key target for the resulting products and services is the farming population of the wheatbelt. This 200,000 $km^2$ region is located in the south-east region of the state and is dominated by rainfed grain and livestock farms.

Understanding how weather and forecast information is used by farmers, and the benefits they gain from improved weather information, is necessary to adequately inform future investments. To date however, appraisals rely on the informal opinions of industry professionals, without evidence obtained through scientific investigation. The objective of this study is to address this gap in knowledge, which endures in Australia and in broadacre agriculture internationally.

The questions addressed in this study include:

- Through which products and services do farmers obtain weather and forecast information (Fig.1)?
- How often do farmers use weather and forecast information?
- Are some groups of farmers accessing this type of information more than others?
- Which decisions on farm are influenced by weather and forecast information?
- What is the extent of these impacts?
- How do different types of information, such as different forecast horizons, impact farmers' decisions?

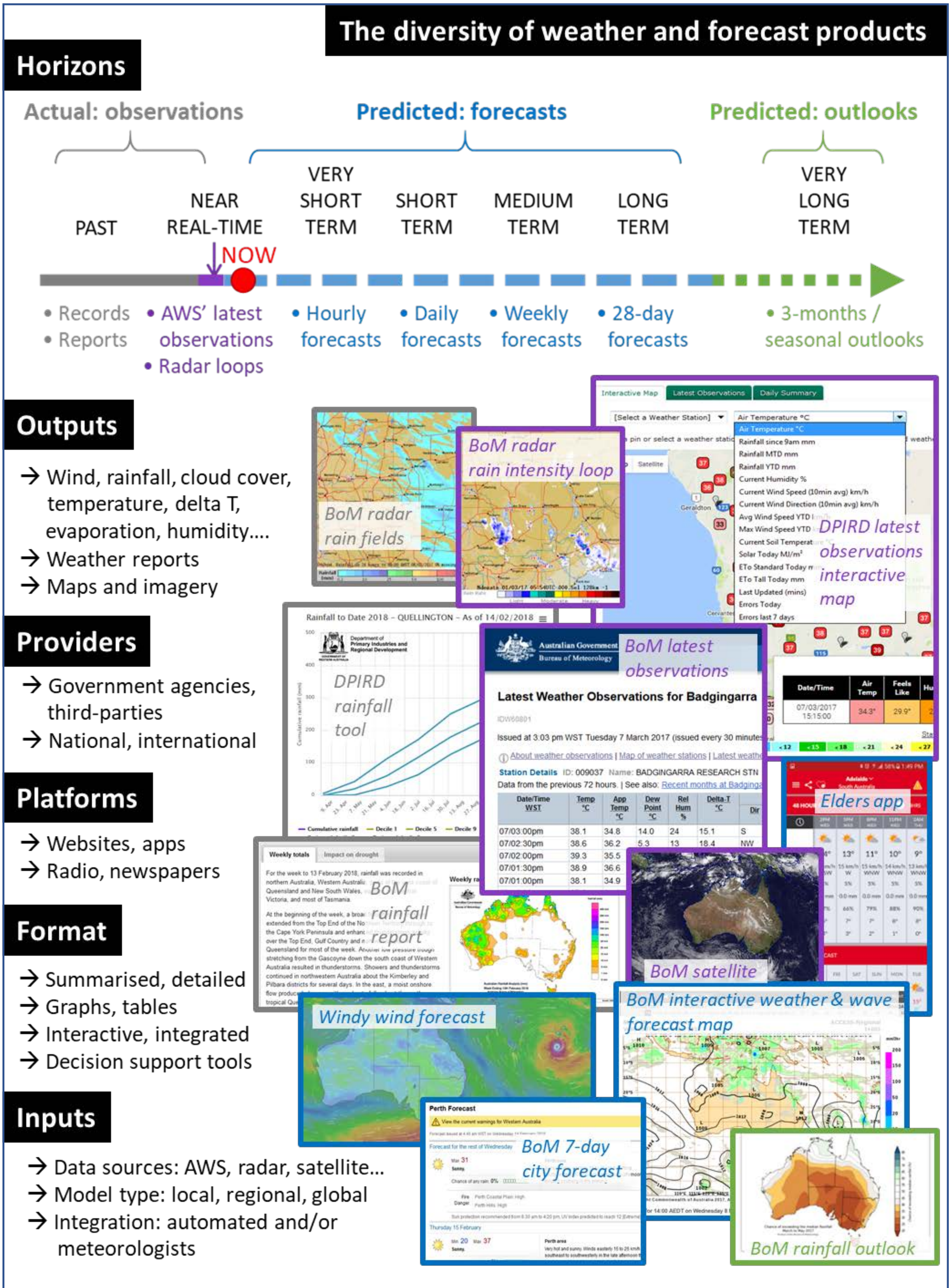



**Fig.1 Examples of the myriad of products available that provide weather and forecast information.** Some products are specifically designed for farmers, such as BoM's agricultural 4-day forecasts, or third-party apps produced by private rural services companies. AWS: Automatic Weather Stations. BoM: Bureau of Meteorology. DPIRD: Department of Primary Industries and Rural Development (formerly DAFWA, Dpt. of Agriculture Western Australia).

## The importance of weather and forecast information to Australian broadacre agriculture

The Western Australian wheatbelt is one of Australia's main grain growing regions. Over ten million tons of grains are produced by about 4,000 rainfed broadacre farms, which includes a third of the country's wheat tonnage (ABARES, 2016). Together with livestock products, this amounts to an approximately five billion dollar industry (ABS, 2016). Any productivity gain is therefore expected to result in large economic benefits.

Weather forecasts are assumed to be important for productivity by improving farmers' decisions, notably by allowing them to conduct more accurate and timely operations (Changnon, 2007; Yates et al., 2016). This appears particularly justified across the Australian southern grainbelt where weather conditions constitute key production factors. Notably, low water availability and extreme variability in annual and seasonal rainfall are considered the most important limitations to grain yields (Hochman et al., 2013; Sprigg et al., 2014). In addition, weather variability has increased with a changing climate (Pook et al., 2012; Raut et al., 2014).

## A historical focus on determining farmers' decision-making processes rather than practices

The overall importance of forecast and weather information to farmers has led the government and the scientific community to produce a variety of weather-related products and services to help farmers make better informed decisions. However, there is almost no information on which products farmers use, and the extent to which the relayed weather and forecast information impacts their practices. These gaps in knowledge are not unique to the Australian broadacre agriculture. Concerns are evident in other countries such as the U.S. where researchers and governments services thrive to better reach out to farmers (Changnon, 2007).

Evidence of these concerns is represented by the great interest there has been in understanding how farmers' decision-making processes help them to adjust their operations according to climatic information. In Australia, research has specifically investigated how broadacre farmers integrate scientific information and advice, to elucidate the thought processes leading to management decisions (McCown et al., 2012). Subsequently, recommendations have been made to increase the adoption of decision support tools, some of them weather-related (Hochman, 2009; Hochman & Carberry, 2011). For instance, it is now understood that farmers usually integrate several sources of information in a progressive, adjustable process. However, other key aspects remain undocumented: which products and services farmers use; whether there are variations in use across the farming population; what is the relative impact of weather and forecast information on farming practices. In Australia, the lack of evidence about the accessibility and use of forecasts by farmers has been recognised (Yates et al., 2016). Even the usefulness for farmers of long-term seasonal forecasts remains little informed, in spite of the large amount of literature produced by the international scientific community on related questions (Klemm & McPherson, 2017). Exceptions exist in the United States, where Takle et al. (2014) drew an overall "climate decision cycle" for corn, and Crane et al. (2010) provided an abundance of insights about farmers decision processes from detailed case studies. In both cases however, quantitative data was lacking to generalise results, and the above questions were not answered. Otherwise, the most relevant information about farmers' use of forecast information has relied on survey data collected in the 1980s-2000s (Changnon, 2004; Artikov et al., 2006; Hu et al., 2006; Frisvold & Murugesan, 2013). Whilst the insights gained from these surveys about the drivers of farmers' behaviour are still valuable, practices have likely evolved, along with demographic changes and technology progresses in rural areas. There is therefore a need to investigate current farmer use of weather and forecast information, and how that use affects their farm practices.

## Current work using farmers' practices relies on assumptions rather than actual data

Reviewers have highlighted the enduring lack of information about farmers' use of weather and forecast information (Kusunose & Mahmood, 2016). Studies that model farmers' decision-making rely on assumptions about farmers' use of weather information. Rather than documenting *actual* practices, such studies address *potential* needs. Hypothetical practices and changes in managements are typically based on anecdotal evidence from industry professionals (Garbrecht et al., 2010; Ghahramani & Moore, 2016) or based on 'commonly accepted' knowledge, such as farmers' tactical adjustments as the year unfolds (Petersen & Fraser, 2001). Other studies include parameters to represent risk aversion (Asseng et al., 2012a), or to account for variations in behaviour through scenario and sensitivity analyses (Asseng et al., 2012b). Behaviour can also be ignored altogether using "perfect knowledge" simulations (Moeller et al., 2008), or replaced by optimised decision scenarios (Shafiee-Jood et al., 2014).

These varied approaches generally gravitate around one major assumption, with one major consequence: weather and forecast information must be important to farmers and their decisions, therefore improvements in forecasting capability must result in great benefits. However, the presence of meteorological information does not necessarily correlate with value for the intended end-users (Leviäkangas, 2009). This could be the case in Australia, where discrepancies remain between business cases that expect large returns on technology investments (e.g. GHD, 2013; AEC, 2014; ESS, 2014), and anecdotal observations reporting mediocre interest from farmers (McCown et al., 2009; Hochman & Carberry, 2011). To avoid repeating this pitfall, documenting farmers' practices and the way in which weather information plays a role in shaping farming practices is a pre-requisite to any economic evaluation effort.

## The challenges in documenting the use of weather and forecast information by farmers

Whilst forecast and weather information appears essential to Australian broadacre farmers, assessing how this information is used is challenging. The large number of production practices and the diversity of farming circumstances in the wheatbelt complicates the question. Weather and forecast information can potentially impact land allocation decisions, tactical operations, input management, and even marketing strategies, all complicated by landscape and social considerations. Timing of seeding, managing fertiliser and pesticides application, and reducing livestock losses are considered particularly important in the Western Australian context (Pook et al., 2009; Asseng et al., 2010; Asseng et al., 2012b; Bell et al., 2013; Burton, 2014; Lacoste et al., 2016, 2018).

In the present study, these challenges were addressed by using a mixed method methodology based on in-depth interviews with farmers. An iterative process permitted to gather detailed yet representative information about a broad range of relevant aspects, and the collection of quantitative data was informed by qualitative information. Such approaches remain rare in Australian agricultural studies (Lacoste et al., 2017), in spite of their potential to investigate complex topics that include human elements (Tashakkori & Teddlie, 2010; Plano Clark & Ivankova, 2016). The next section details the methods used, before presenting results in 4 themed sections: *(i)* farming characteristics, *(ii)* products used, *(iii)* impact on practices, and *(iv)* farmers views.

# References


ABARES. (2016). Agricultural commodity statistics 2016. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).

ABS. (2016). *Value of Agricultural Commodities Produced, Australia, 2014-15*. Canberra: Australian Bureau of Statistics.

AEC. (2014). Technology in Agriculture, Department of Agriculture and Food - Final Report. Perth: AEC Group Pty Ltd.

Artikov, I., Hoffman, S. J., Lynne, G. D., Pytlik Zillig, L. M., Hu, Q., Tompkins, A. J., Hubbard, K. G., Hayes, M. J. & Waltman, W. (2006). Understanding the Influence of Climate Forecasts on Farmer Decisions as Planned Behavior. *Journal of Applied Meteorology and Climatology, 45*, 1202-1214.

Asseng, S., Dray, A., Perez, P. & Su, X. (2010). Rainfall–human–spatial interactions in a salinity-prone agricultural region of the Western Australian wheat-belt. *Ecological Modelling, 221*(5), 812-824. doi:10.1016/j.ecolmodel.2009.12.001

Asseng, S., McIntosh, P. C., Wang, G. & Khimashia, N. (2012a). Optimal N fertiliser management based on a seasonal forecast. *European Journal of Agronomy, 38*, 66-73. doi:10.1016/j.eja.2011.12.005

Asseng, S., Thomas, D., McIntosh, P., Alves, O. & Khimashia, N. (2012b). Managing mixed wheat–sheep farms with a seasonal forecast. *Agricultural Systems, 113*, 50-56. doi:10.1016/j.agsy.2012.08.001

Bell, L. W., Moore, A. D. & Kirkegaard, J. A. (2013). Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia. *European Journal of Agronomy*. doi:10.1016/j.eja.2013.04.007

Burton, R. J. (2014). The influence of farmer demographic characteristics on environmental behaviour: a review. *Journal of Environmental Management, 135*, 19-26. doi:10.1016/j.jenvman.2013.12.005

Changnon, S. A. (2004). Changing uses of climate predictions in agriculture: implications for prediction research, providers, and users. *Weather and forecasting, 19*(3), 606-613.

Changnon, S. A. (2007). The Past and Future of Climate-Related Services in the United States. *Journal of Service Climatology, 1*(1), 1-7.

Crane, T. A., Roncoli, C., Paz, J., Breuer, N., Broad, K., Ingram, K. T. & Hoogenboom, G. (2010). Forecast Skill and Farmers' Skills: Seasonal Climate Forecasts and Agricultural Risk Management in the Southeastern United States. *Weather, Climate, and Society, 2*(1), 44-59. doi:10.1175/2009wcas1006.1

ESS. (2014). Western Australia radar network, costs and benefits: Environmental Systems & Services Weather Tech Pty Ltd.

Frisvold, G. B. & Murugesan, A. (2013). Use of Weather Information for Agricultural Decision Making. *Weather, Climate, and Society, 5*(1), 55-69. doi:10.1175/wcas-d-12-00022.1

Garbrecht, J. D., Zhang, X. C., Schneider, J. M. & Steiner, J. L. (2010). Utility of seasonal climate forecasts in management of winter-wheat grazing. . *Applied Engineering in Agriculture, 26*(5), 855-866.

Ghahramani, A. & Moore, A. D. (2016). Impact of climate changes on existing crop-livestock farming systems. *Agricultural Systems, 146*, 142-155. doi:10.1016/j.agsy.2016.05.011

GHD. (2013). Orana Region Organisation of Councils - Weather Radar Project. Dubbo: GHD.

Hochman, Z. (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*.

Hochman, Z. & Carberry, P. S. (2011). Emerging consensus on desirable characteristics of tools to support farmers' management of climate risk in Australia. *Agricultural Systems, 104*(6), 441-450. doi:10.1016/j.agsy.2011.03.001

Hochman, Z., Carberry, P. S., Robertson, M. J., Gaydon, D. S., Bell, L. W. & McIntosh, P. C. (2013). Prospects for ecological intensification of Australian agriculture. *European Journal of Agronomy, 44*, 109-123. doi:10.1016/j.eja.2011.11.003

Hu, Q., Pytlik Zillig, L. M., Lynne, G. D., Tomkins, A. J., Waltman, W. J., Hayes, M. J., Hubbard, K. G., Artikov, I., Hoffman, S. J. & Wilhite, D. A. (2006). Understanding Farmers' Forecast Use from Their Beliefs, Values, Social Norms, and Perceived Obstacles. *Journal of Applied Meteorology and Climatology, 45*, 1190-1201.

Klemm, T. & McPherson, R. A. (2017). The development of seasonal climate forecasting for agricultural producers. *Agricultural and Forest Meteorology, 232*, 384-399. doi:10.1016/j.agrformet.2016.09.005

Kusunose, Y. & Mahmood, R. (2016). Imperfect forecasts and decision making in agriculture. *Agricultural Systems, 146*, 103-110. doi:10.1016/j.agsy.2016.04.006

Lacoste, M., Lawes, R., Ducourtieux, O. & Flower, K. (2016). Comparative agriculture methods capture distinct production practices across a broadacre Australian landscape. *Agriculture, Ecosystems & Environment, 233*, 381-395. doi:10.1016/j.agee.2016.09.020

Lacoste, M., Lawes, R., Ducourtieux, O. & Flower, K. (2017). Methods to Study Agricultural Systems. In Lichtfouse, E. (Ed.), *Sustainable Agriculture Reviews* (Vol. 25). Cham: Springer.

Lacoste, M., Lawes, R., Ducourtieux, O. & Flower, K. (2018). Assessing regional farming system diversity using a mixed methods typology: the value of comparative agriculture tested in broadacre Australia. *Geoforum, 90* 183–205. doi:10.1016/j.geoforum.2018.01.017

Leviäkangas, P. (2009). Valuing meteorological information. *Meteorological Applications, 16*(3), 315-323. doi:10.1002/met.122

McCown, R. L., Carberry, P. S., Dalgliesh, N. P., Foale, M. A. & Hochman, Z. (2012). Farmers use intuition to reinvent analytic decision support for managing seasonal climatic variability. *Agricultural Systems, 106*(1), 33-45. doi:10.1016/j.agsy.2011.10.005

McCown, R. L., Carberry, P. S., Hochman, Z., Dalgliesh, N. P. & Foale, M. A. (2009). Re-inventing model-based decision support with Australian dryland farmers. 1. Changing intervention concepts during 17 years of action research. *Crop and Pasture Science, 60*(11), 1017. doi:10.1071/cp08455

Moeller, C., Smith, I., Asseng, S., Ludwig, F. & Telcik, N. (2008). The potential value of seasonal forecasts of rainfall categories—Case studies from the wheatbelt in Western Australia's Mediterranean region. *Agricultural and Forest Meteorology, 148*(4), 606-618. doi:10.1016/j.agrformet.2007.11.004

Petersen, E. H. & Fraser, R. W. (2001). An assessment of the value of seasonal forecasting technology for Western Australian farmers. *Agricultural Systems, 70*, 259–274.

Plano Clark, V. L. & Ivankova, N. V. (2016). *Mixed Methods Research: A Guide to the Field*. Thousand Oaks: SAGE Publications, Inc.

Pook, M., Lisson, S., Risbey, J., Ummenhofer, C. C., McIntosh, P. & Rebbeck, M. (2009). The autumn break for cropping in southeast Australia: trends, synoptic influences and impacts on wheat yield. *International Journal of Climatology*, *29*(13), 2012-2026. doi:10.1002/joc.1833

Pook, M. J., Risbey, J. S. & McIntosh, P. C. (2012). The Synoptic Climatology of Cool-Season Rainfall in the Central Wheatbelt of Western Australia. *Monthly Weather Review*, *140*(1), 28-43. doi:10.1175/mwr-d-11-00048.1

Raut, B. A., Jakob, C. & Reeder, M. J. (2014). Rainfall Changes over Southwestern Australia and Their Relationship to the Southern Annular Mode and ENSO. *Journal of Climate*, *27*(15), 5801-5814. doi:10.1175/jcli-d-13-00773.1

Shafiee-Jood, M., Cai, X., Chen, L., Liang, X.-Z. & Kumar, P. (2014). Assessing the value of seasonal climate forecast information through an end-to-end forecasting framework: Application to U.S. 2012 drought in central Illinois. *Water Resources Research*, *50*(8), 6592-6609. doi:10.1002/2014wr015822

Sprigg, H., Belford, R., Milroy, S., Bennett, S. J. & Bowran, D. (2014). Adaptations for growing wheat in the drying climate of Western Australia. *Crop and Pasture Science*. doi:10.1071/cp13352

Takle, E. S., Anderson, C. J., Andresen, J., Angel, J., Elmore, R. W., Gramig, B. M., Guinan, P., Hilberg, S., Kluck, D., Massey, R., Niyogi, D., Schneider, J. M., Shulski, M. D., Todey, D. & Widhalm, M. (2014). Climate Forecasts for Corn Producer Decision Making. *Earth Interactions*, *18*(5), 1-8. doi:10.1175/2013ei000541.1

Tashakkori, A. & Teddlie, C. (2010). *Sage handbook of mixed methods in social & behavioral research*. Thousand Oaks: Sage.

Yates, D., Vervoort, R. W., Minasny, B. & McBratney, A. (2016). The history of using rainfall data to improve production in the grain industry in Australia - from Goyder to ENSO. *Crop and Pasture Science*, *67*(5), 467. doi:10.1071/cp15053

# 2. Material & methods

In-depth interviews across 3 study areas: 51 respondents, 37 farms

## Overview and rationale

The practices of farmers regarding the use of weather and forecast information were investigated along three lines:

(i) What sources of information farmers use and why

(ii) How that information impacts farming practices

(iii) What factors impact the use of weather and forecast information, most notably:

- farm characteristics (e.g. farm size, enterprise mix, technological level)
- farmer characteristics (e.g. age, experience, opinions and perceptions)

To achieve this, an exploratory approach based on detailed interviews was used that allowed answering two challenges:

- *The complexity of the topic*: this study involved decision-making processes, that are typically influenced by multiple factors.
- *The lack of prior research*: very limited research had been conducted on the topic. Whilst other studies may have made assumptions about farmers' use of weather information and consulted experts, no existing research could inform what data was most important to collect.

The exploratory methodology used here was based on mixed methods principles, i.e. combining quantitative and qualitative methods using detailed interviews. Emphasis was placed on:

- Covering a broad range of topics, including promoting discussion to identify areas of interest that could not be anticipated earlier because of lack of prior information.
- Contextualising quantitative data with qualitative information.
- Using a representative sample of the farming population by actively reducing biases (random selection of farms rather than using listings, cold-calling recruitment to limit respondent self-selection, one-on-one interviews to avoid peer-pressure).

The interview design was approved by the Human Research Ethics committee of UWA (RA/4/1/9051). The Participant Information Form is provided in Appendix A.

## Locations and respondent recruitment

Respondents were sought from three locations chosen in relation to the Doppler radars (Fig.2):

- *South-West Pingelly*, that had radar coverage for several years from the Serpentine radar;
- *Newdegate*, and *Cunderdin* near Doodlakine, that had radar coverage for one and half a year, respectively.

These locations were chosen to capture the impacts of the new Doppler radars (data not presented here).

Data was collected during July-October over one week of fieldwork for Pingelly, one week of fieldwork for Newdegate (both face-to-face interviews), and two weeks of interviews for Cunderdin (phone interviews). For all three locations, farms were identified while driving in the studied area (scouting) or based on recommendation from previous respondents (snow-balling), and selected at random. Farmers were recruited directly by knocking on doors, without prior appointment (cold-calling). The response rate was 100%.

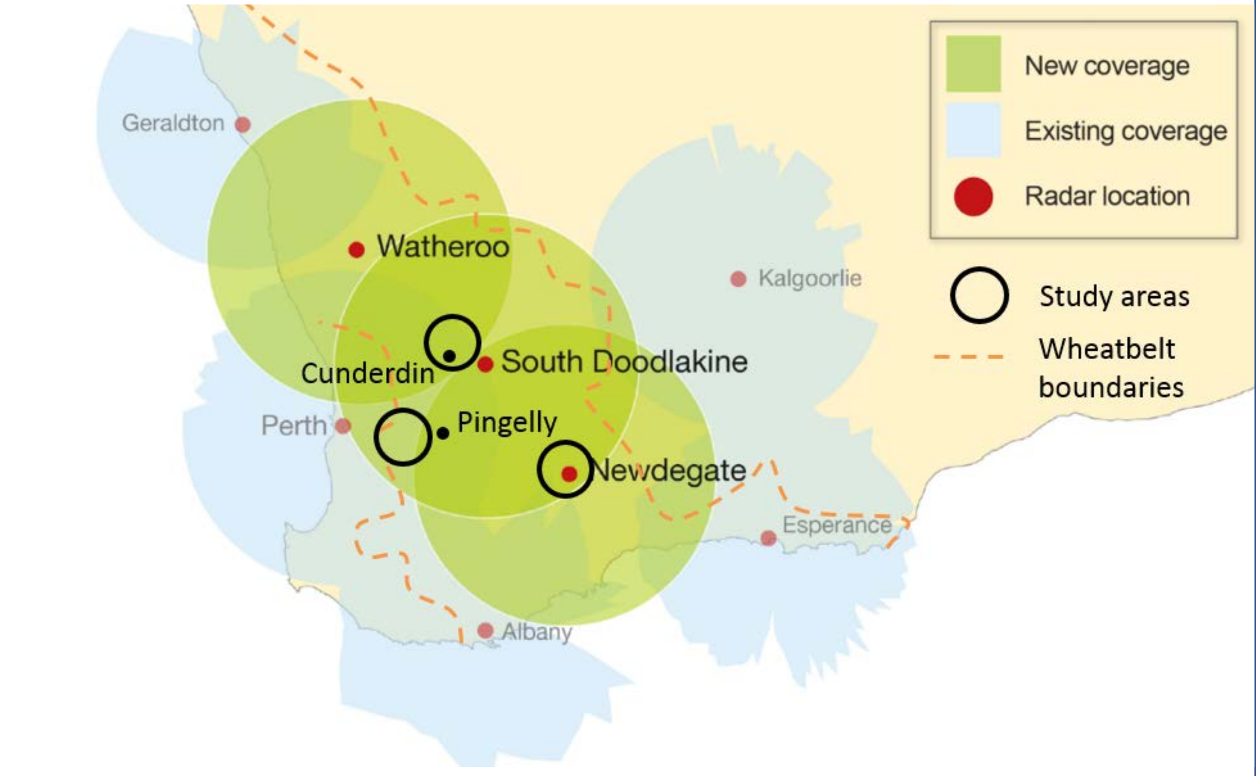



**Fig.2 Radar coverage and fieldwork locations.** The radars in Newdegate (installed September 2016), South Doodlakine (February 2017), and Watheroo (April 2017) are part of the most recent investments in weather and forecast technology in the Western Australian wheatbelt and include Doppler technology. Prior to their construction, there was limited to no radar coverage in the central wheatbelt. A study area covered by the Serpentine radar near Perth (installed in 2008, upgraded to Doppler in 2014) was included in the study to ensure the data collected in Newdegate and Cunderdin reflected established practices.

## Interview design

Prior to designing the interview guidelines, an understanding of *potential* benefits was gained through the literature review (see introduction), and was further informed through consultations with six industry experts (two agronomy consultants, two grower group coordinators, two researchers from UWA and CSIRO). However, considering the lack of information on *actual* benefits, reliance on pre-existing assumptions was kept minimal. Instead, the interviews were designed to cover a wide range of potentially relevant aspects, using a flexible in-depth, semi-structured format. The interview guidelines were further refined during the first interviews in Pingelly. Table 1 lists the topics addressed in the interviews; the final guidelines are provided in Appendix B.

Interviews lasted between 20 minutes to 1 hour; typically longer in Pingelly (refining questions and investigating potential areas of interest), and shorter in Cunderdin (focus on most important aspects). A situation of saturation occurred after 25 interviews (achieved during fieldwork at Newdegate), at which point no new important information was uncovered through exploration. An additional 20 interviews were conducted in order: *(i)* to be more representative of the wheatbelt diversity by including a third location where farming situations were known to be different (more cropping in Cunderdin than in Pingelly and Newdegate); *(ii)* to ensure sufficient respondent numbers to avoid issues related to very small samples (e.g. over-representation of rare situations); and *(iii)* to ensure sufficient data would be collected for quantitative analysis.

Table 1. Progression of semi-structured interviews with farmers.

| *Topic discussed* | *Questions* | *Variables and factors investigated* |
|---|---|---|
| **1. Farm** | | |
| *Land use* | Total arable, cropped, sheep | Farming system (farm type) |
| *Workforce* | Full-Time Equivalents required on the farm: manager, family incl. semi-retired parents, full-time employees | Farming system (farm size) |
| *Machinery* | Width of seeder and harvester, renewal strategy | Machinery capacity<br>Technological level index |
| *Manager* | Age, experience, management emphasis if any | Age, experience (years)<br>Management emphasis |

| | | |
|---|---|---|
| **2. Technology** | | |
| *Coverage* | Area with sufficient mobile phone reception | In-field mobile access |
| *Technologies* | Degree of reliance on computer for office work; collection and use of field data (e.g. yield mapping, variable rate); moisture probes; farm network setup; degree of interest in further investing and developing these tools | Technological level index |
| **3. Products** | | |
| *Main sources* | Among all that is available, main weather and forecast information products and tools used | Main sources: product nature and numbers |
| *Reason for choices* | Reasons for using these sources and not others | Reasons<br>Opinion of BoM |
| *Frequency of access* | Acknowledging that access likely depends on the season and the activities, typical frequency of accessing these products | Avidity profile (relative interest) |
| *Specific products* | Government (BoM and DPIRD) products and services related to weather and forecasts, radio, TV | Uses and reasons<br>Reasons for (not) use |
| *Radar features* | Use of features, impact on overall management and on very short-term forecast confidence (Newdegate & Cunderdin only) | Specific feature uses<br>Management change*<br>Confidence/risk change* |
| **4. Practices** | | |
| *Seeding* | Start date, shift duration, capacity situation (land/labour/equipment constrains), seeding plan strategy (relative importance of past and forecasted rainfall), impact of forecast and radar | Forecast confidence<br>Relative impact of weather conditions and forecasts on practices |
| *Harvest* | Impact of forecast and of radar on weather-related losses, constraints | Farm constrains |
| *Spraying* | Average total spending /ha/year*, area sprayed under sub-optimal conditions*, area re-sprayed*, estimated related yield loss*, loss of chemical tanks*, impact of forecast and radar, use of indicators (latest observations) | Seeding: Forecast profiles<br>Spraying: Indicator |
| *Fertilising* | Average total spending /ha/year*, impact of forecast and radar, strategy details | |
| *Sheep* | Impact of forecast and radar on weather-related losses | |
| *Others* | Any other aspects weather-related (e.g. extreme events, insurance) impacted by forecast and radar | |
| **5. Opinions** | | |
| *Future investments* | What would invest in, what are the gaps, what to do or improve next (technologies, extension…) | Gaps |
| *Own interest* | Read online about weather and climate (events, interpretation…) for own interest | Specific product uses |
| *Forecast performance* | Own impression of overall forecast performance along the years | Perception of forecast skill improvement<br>Opinion of BoM |

* not presented in this report

# 3. Results

## Sample overview

A total of 45 interviews were conducted involving 57 people (84% male). Most interviews were conducted one-on-one, however family members sometimes joined in and contributed precisions. Answers were therefore collected for 51 respondents across 37 farms. All respondents were engaged in farming activities, with 80% of the sample represented by managers (all males, average age: 49), and the remainder mainly consisting of family members (18%: wife, parent, son; 2%: employee).

## Results structure

The next sections present the main results of the study, organised in 4 themes:

- *Sample characteristics:* the sample and the regions studied are presented, as well as important variables for which no impact on farmers' use of weather and forecast information was found.
- *Weather products used*: the main sources of information used by farmers, as well as an investigation of specific product and services.
- *Impact on practices*: relative impact (actual and potential) on the main activities of farmers.
- *Farmers views:* results about farmers opinions and perception that provided a suited conclusion to the results of this study

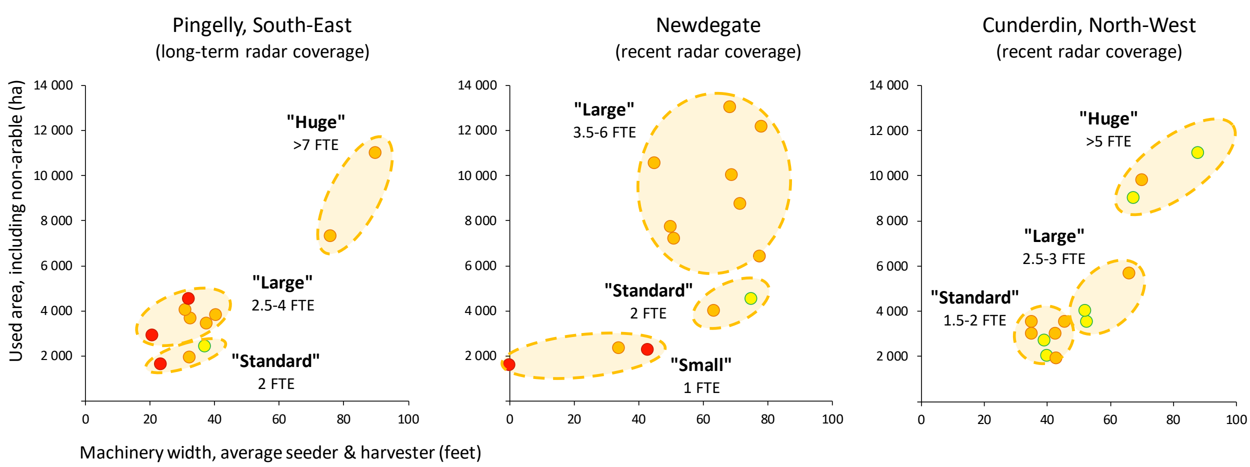
# 3.1 Farming characteristics

No impact detected from major structural farm variables

# Agricultural profiles

The agricultural systems present in the three study areas were similar in size (spanning 2,000–12,000 ha) and enterprise mix. Most farms implemented a combination of cropping and livestock enterprises with overall very similar practices: one crop a year sown in April-May and harvested in October-December; rotations mostly involving wheat, barley, canola, lupin and volunteer pastures; livestock mainly represented by sheep, and rarely by cattle. Overall, 14% of farms specialised in livestock, 22% in crops, and 65% were mixed farms.

The main dissimilarities regarded the distribution of farm sizes and the relative importance of crops and livestock enterprises (Fig.3). These likely reflect geographical attributes. In hilly and wetter Pingelly, livestock activities covered half the land used, with most farms under 4,000 ha. In the mostly flat and heavy-textured land surroundings Newdegate, livestock was slightly less prominent but farms were almost twice larger. In the undulating sandplains dominating Cunderdin, the distribution of farm size was similar to that of Pingelly with a reverse enterprise emphasis (over 80% of the used land cropped), and with nearly half the farms in the sample fully specialising in cropping.




| Location | Farms | Respondents |
|---|---|---|
| Pingelly | 11 | 16 |
| Newdegate | 13 | 18 |
| Cunderdin | 13 | 17 |
| *Total* | *37* | *51* |

**Farm types:** Cropped area (% used): **Livestock specialists** < 25%; **Mixed crop/livestock** 30-85%; **Cropping specialists** 100%

**Farm sizes:** Defined jointly by area, machinery capacity, and the amount and nature of the workforce (i.e. family/employees; FTE = Full-Time Equivalent)

**Fig.3 Comparing farming systems.** In spite of differences between regions, farming businesses can be compared using relative "farm size" and "farm type" criteria. These criteria were found to reflect differences in structure and functioning in the Cunderdin regions that are likely to apply to other regions in the Australian wheatbelt (for more information see Lacoste (2018), referenced in the Introduction). For instance, "Large" and "Huge" "Cropping specialists" are more likely to invest in recent technologies and have more time to dedicate to other activities such as, potentially, sourcing weather and forecast information. However, no differences were found between farm sizes and the use of weather and forecast information. The only exception was "Cropping specialists", who are using more spraying indicators than "Mixed farmers"; the smallest farmers were also found to not use much weather and forecast information, however this was explained by low computer literacy rather than farming system characteristics (see next sections 3.2).

## Standard farm and farmer characteristics have limited impact

Farm characteristics were investigated for their potential impact on farmers' use of weather and forecast information. This was justified by *(i)* the hypothesis that farms equipped with more modern technology may have been more likely to make greater use of information technologies, including that related to weather and forecast; and *(ii)* previous findings regarding farm type and farm size impacting farmer's practices and level of equipment (Fig.3). This study confirmed that the greater the area cropped, the greater the technological level of the farm was (Fig.4). However, **no impact of location, farm type, cropped area, technological levels, or mobile coverage on the overall use** of weather and forecast information could be found.

It is possible that the sample was too small to identify the impact of farm structural characteristics, or that confounding factors exist that were not identified. However, sample size did not prevent the identifications of other strong relationships, suggesting that sample size was not an issue (Fig.4). A more likely explanation is that there is, indeed, no or little impact of farm characteristics on that use. This is probably because weather and forecasts are so important in farming that related information overhauls major structural differences.

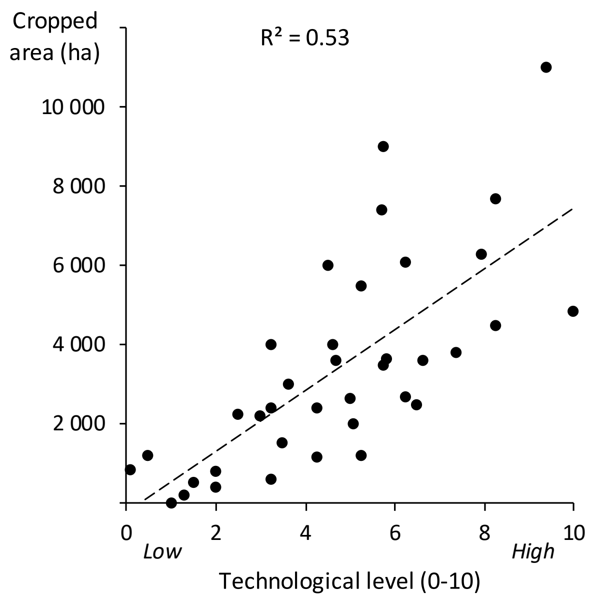



**Fig.4 Farm characteristics: cropped area strongly correlates to technological level.** This index integrates machinery renewal strategy (purchase type and turnover speed), computer reliance, and precision agriculture equipment. Larger farmers who emphasise cropping over livestock activities are commonly thought to have greater reliance on modern technologies. The relationship was verified here, however no links with the use of weather and forecast information was found (Fig.5).

There are two important implications of these findings:

- When building models, forecasts benefits should not be presumed to be mostly relevant to farmers who are larger, crop larger areas, or are equipped with more modern technology.
- Reliance on technologies and on information are not necessarily correlated.

**A common hypothesis is that larger, crop-dominant farms make more use of technologies and information. Structural farm characteristics were found to be indeed related to the technological level of farms, however no relationship with the use of weather and forecast information was found.**

**A likely explanation is that this information is of such importance for farmers that it overhauls the diversity of farming situations: it is relevant and useful to all or, at least, a great majority.**

# 3.2 Products used

- "Avidity" for weather & forecast information
- Main sources & reasons
- Use of specific products
- Latest observations for spraying

## Overview

Respondents were asked how often they typically accessed weather and forecast information, which products they commonly used, and why they choose to use these. Answers to these open-ended questions permitted to assess the "avidity" for weather and forecast information (i.e. keenness and interest), what are the main products used by farmers, and the reasons underlying these choices.

Following this, yes/no questions were asked about specific products or features to gather additional information.

Finally, farmers were asked yes/no questions about which latest observations they use for spraying decisions.

## Avidity

The importance of weather and forecast information to farmers was confirmed, with **the vast majority of respondents (88%) accessing it frequently** (Fig.5a). In facts, almost 60% of respondents accessed this type of information "more than required" i.e. typically several times a day, and 20% declared themselves "addicted" (self-confessed "weather-enthusiast", "weather is my business", "always, always look at it", etc.).

How often information was accessed was highly correlated with the number of sources consulted. **Most farmers accessed several products** on a regular basis, on average four-five different products (Fig.5a). Nearly all these main sources were online-based products accessed via computers, smartphones, and tablets.

**No relationship between variables such as farm size, cropping emphasis, technological level or age** with farmers' avidity for weather and forecast information was found (Fig.5b-e). Although farmers who accessed such information the least were among the oldest in the sample (Fig.4b), it appeared that their limited access was not because of age but because of low computer literacy. These farmers typically relied on personal observations or other members of the farming business.

**The great majority of farmers access weather and forecast information frequently, through several online products. Farmers who did not use weather and forecast information represented a minority and typically lacked basic computer skills. Age had no impact: older farmers accessed this information as much as younger farmers.**

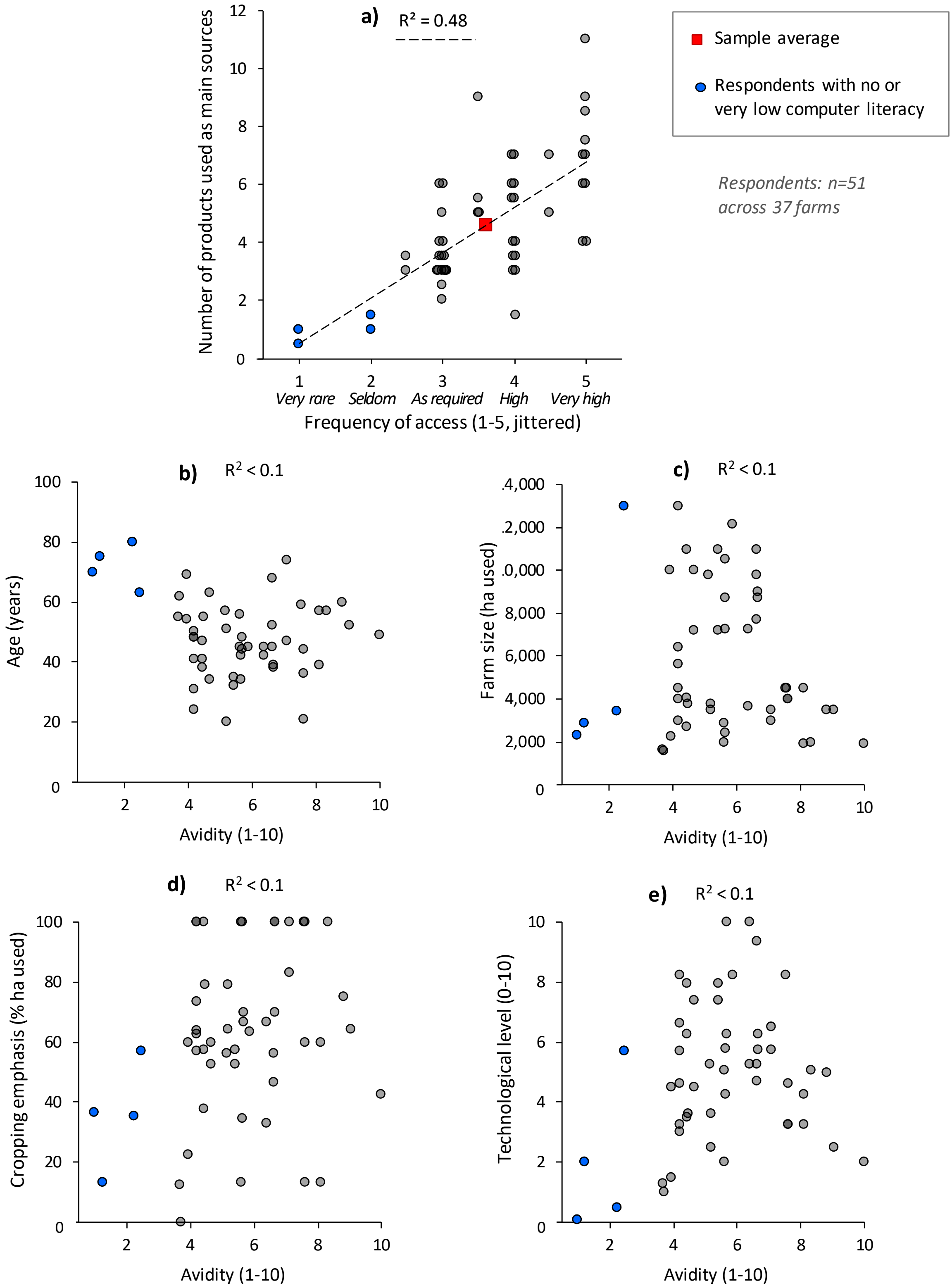
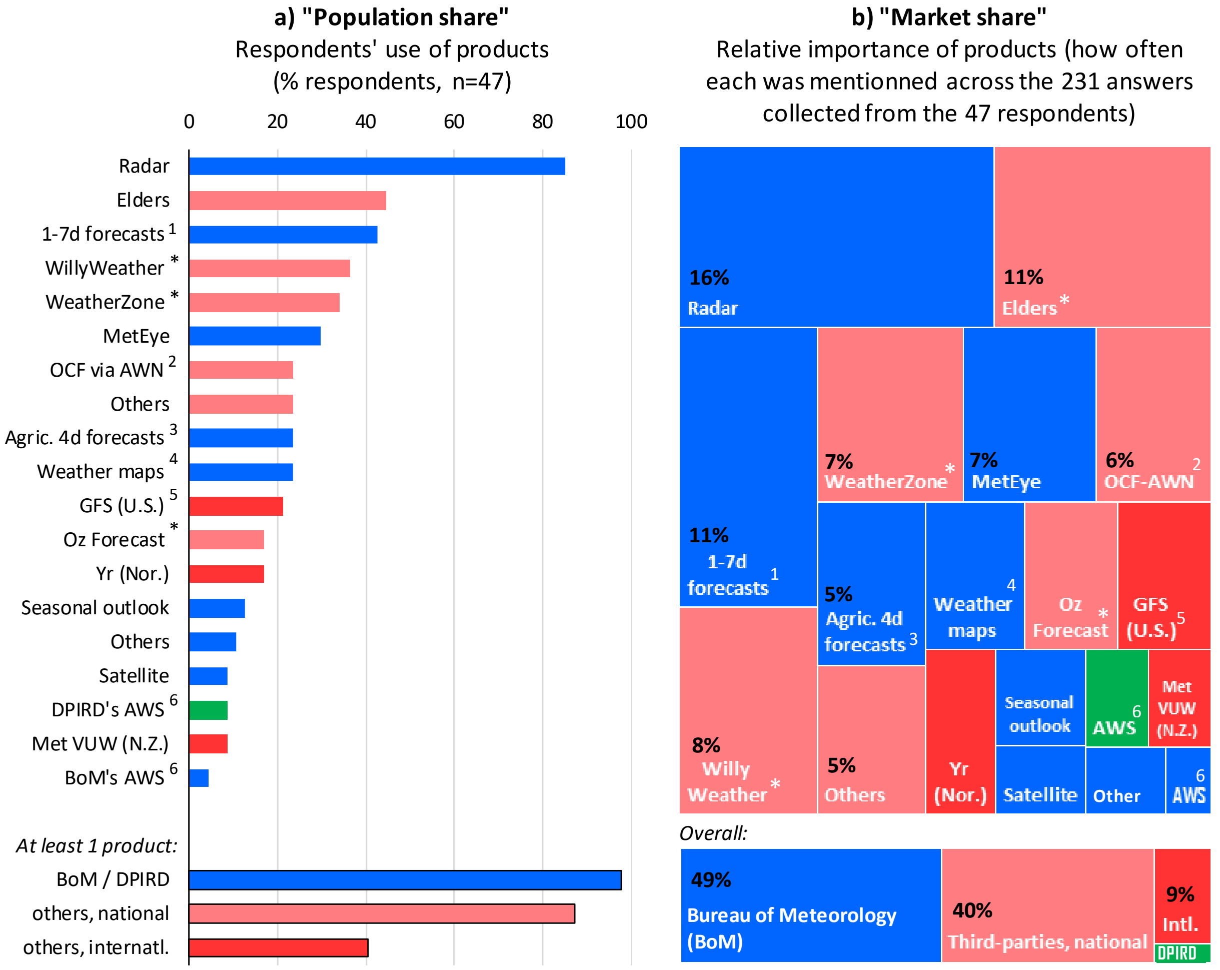



**Fig.5 "Avidity" for weather and forecast information.** This index assessing keenness and interest consists of the addition of the following two (standardised) variables: **frequency of access and number of products (a).** The high correlation between these two variables indicates that, generally, the more frequently farmers access information, the more sources they consult. The relationship did not change when omitting respondents with low computer literacy ($R^2$ reduced to 0.35). "As required" is typically defined as "almost every day during the growing season, several times a day at spraying and whenever else needed, and less often in summer". No relationship was identified between **avidity and other variables (b-e)**.

## Main information sources

When asked what they mainly used to access weather and forecast information, farmers named 2 to 11 different products. From all 47 respondents, this resulted in a total of 231 answers gathered, distributed over 20 products, half of which provided by the government (Fig.6). The vast **majority of respondents (85%) consulted a variety of products from BoM and third-party platforms** (4-5 products on average per respondents). All the respondents accessed radar imagery as well as daily and weekly forecasts, from various sources. On the other hand, automated weather stations and seasonal outlooks were seldom mentioned as main sources.

In Fig.6, the “population share” and the “market share” differ due to respondents using a different number and set of products each. For instance, the radar was mentioned by almost everyone, however many other products were named as well, reducing its relative importance: the radar is used by all but represents only one source of information among many others. Fig.6b also highlights that there is not one consistent pattern of use: a few farmers only use BoM products, most combine them with third-parties, which vary as well since farmers’ preferred apps vary. For instance, government products do not have much presence at all in the “weather app market”, which is currently dominated by Elders.




* Primarely accessed via apps on mobile phones rather than websites on computers
1 Daily and 7-day forecasts, town and district based
2 OCF (Operational Consensus Forecasts) provided by BoM but accessed via AWN (AustralianWeatherNews.com)
3 BoM "Water and the Land - For Agriculture and Natural Resources Management", mainly 4-day forecast maps
4 BoM "Weather maps": forecasts, synoptic and barometric charts, poles, oceans
5 GFS (Global Forecast System) mainly accessed via noaa.org and wxmaps.org
6 AWS (Automatic Weather Stations): past observations

**Fig.6 Farmers' main sources of weather and forecast information.** The 47 respondents named 2 to 11 products each, spanning a variety of government webpages, third-party mobile phone apps, and even international model outputs. A point system was used to reflect the relative importance of each product: 1 most often, sometimes 0.5 when a source was mentioned but specified not being used as much, or 2 for products strongly emphasised as being the main source of information. Results are displayed here in two ways: **a) uses within the population** and **b) relative importance of each product** among all those mentioned. For instance, almost a quarter of farmers mentioned the agricultural forecasts produced by BoM, however these only represented 5% of all the products used.

## Reasons for using information source

Respondents provided one to three reasons supporting their multiple product choices (Fig.7). The main reasons were ease of use and performance.

**Ease of use** mostly referred to the convenience of compact formats that condense all required information while avoiding unnecessary details (e.g. the all-on-one-screen format of the Oz Forecast app and the simplicity of the Elders app). BoM products typically scored low on that criteria compared to third-parties. Many respondents who mentioned ease of use as a reason often specified they had no time to look and compile information themselves, and therefore required quick solutions.

**Performance** referred to accuracy and reliability. In most cases, the local relevance of BoM was highlighted, but not always. Although most farmers were aware that third-party products source their data mainly from BoM, many highlighted discrepancies and varying performances outputs for their area.

Two other reasons explained why most farmers use multiple products. One was the requirement for **specific features**, for instance the percentage likelihood of OCF outputs, the live wind maps of WillyWeather, the combined 48-hour and 28-day forecasts of Elders, or the global outputs provided by GFS. The second reason was to **compare several perspectives** for respondents to build their own "whole picture" of their local weather and forecast. As with performance, variations between products were highlighted to justify this.

Lastly, a smaller proportion of farmers **did not actively choose products**, relying instead on websites coming up first in search engines, apps pre-installed on their devices (e.g. WeatherZone), or recommendations (e.g. WillyWeather or Windy). These respondents echoed many others who mentioned difficulties in finding products on the BoM websites, relying on products they had bookmarked a long time ago without further or recent investigation.

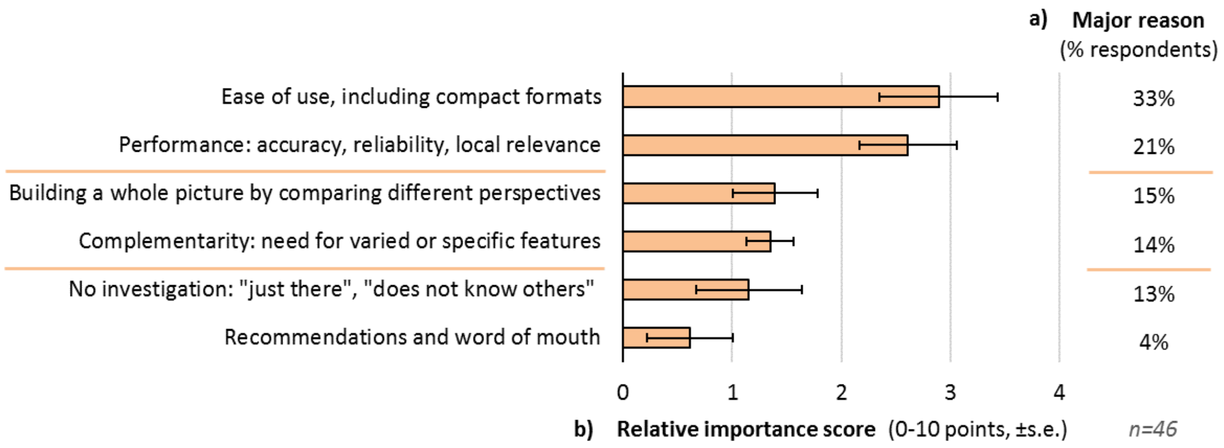



**Fig.7 Farmers' reasons for choosing their main sources of information.** Answers were quantified in two ways. **a) Major reason**: the primary reason mentioned by respondents. **b) Relative importance scores**: 10 points were distributed between answers for each respondent (e.g. when two answers given: 8 points for the main reason, 2 points for the minor one, 0 for the others not mentioned). Averaged importance scores are low as most respondents gave only one to three responses, and must therefore be understood relatively to each other.

**Farmers accessed a variety of products from the Bureau of Meteorology and third-parties. Their reasons to prefer some products over others included ease of use, perceived performance, specific features, and the need to compare different outputs.**

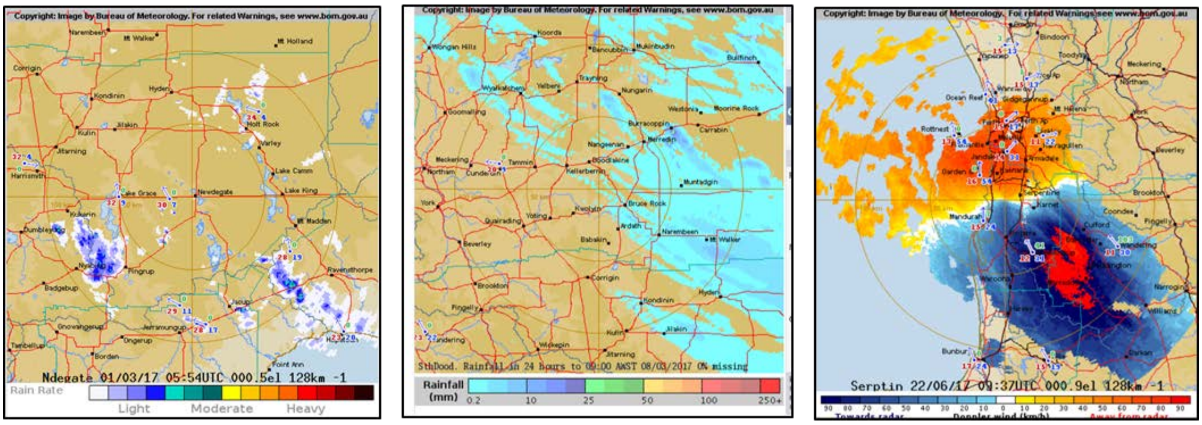
**It was notable that farmers knew weather data is sourced from BoM, yet they considered there is great discrepancies in forecasts. This is symptomatic of either mis-perceptions about performances, or of important differences in data integration and outputs between platform providers.**

**To better suit and inform farmers' choices, BoM could consider providing:**
**- more information about the range of products and features available to farmers**
**- evidence of product accuracy and reliability, and comparisons of forecast performance across products**

## Specific products and services

Additional questions were asked to further inform farmers' use of specific products (considered main sources of information or not), with a focus on:

- Products relevant to the project: Doppler radar features (Fig.8) and BoM extension activities
- Products more broadly related to long-term government-funded initiatives: e.g. MetEye, BoM's app, weather-related initiatives from DPIRD (formerly DAFWA, Department of Agriculture of Western Australia), automated weather stations
- Seasonal outlooks, because of considerable interest from the international research community
- Non-online products, i.e. radio and television, because these had been little mentioned in earlier responses
- The overall interest for more meteorological information available online.



a) Rain rates b) Rainfields c) Doppler wind

**Fig.8 Radar imagery.** Examples of **a) Rain rates**: dynamic qualitative output representing rainfall intensity; **b) Rainfields**: quantitative outputs based on rain rates calibrated with on-the-ground weather stations; **c) Doppler wind**: dynamic output representing speed and direction of wind relative to the radar position. Although all respondents accessed rain rate loops, less than 50% accessed rainfields and only a quarter had accessed the Doppler wind imagery, mainly because being unaware of these features (Fig.9).

Important results included (Fig.9):

- The **rainfields** and **Doppler wind** features of the radar are greatly under-used, often due to lack of awareness (they appear only as small links in the corner of the radar webpage).
- The use of **MetEye** was hindered by slow downloads and lags, as well as a lack of awareness. This flagship platform of BoM was otherwise valued by those who use it.
- The **BoM app** and **DPIRD's weather-related tools** are little valued and little used by farmers (less than 25% respondents use either, and mostly occasionally).
- **Seasonal outlooks** and **automated weather stations** from both government agencies were little mentioned as main sources, but were still accessed by almost half and two-thirds of the respondents, respectively. This demonstrates, especially for the stations, that they may not come much to farmers' mind but are still important for many of them. For instance it is possible that the stations have become very familiar and 'taken for granted' without, for instance, the exposure and publicity that the new radars benefit from. It is also unclear whether farmers know the role of automatic weather stations in forecasting. For instance, no farmer with whom the topic was discussed knew that rainfields were produced from radar outputs calibrated with station observations.
- Farmers do not rely on the **radio** and **television** weather reports and forecasts, that they consider are not local enough. However, many respondents still listen to the weather segment on the radio that is often switched on in tractors, and several mentioned enjoying **weather-related programs**.

With regards to extension services:

- BoM's extension efforts through **online videos and outreach activities** have had very little impact. Very few respondents were aware of either.
- Comparatively, the **radio segment on the ABC Country Hour** that explains meteorological events and mechanisms is very popular and trusted.
- Three quarters of farmers in the sample would potentially be interested in attending BoM **outreach activities** in their localities (if "time permitting"); no respondent had previously heard of the eConnected Grainbelt Project, an initiative from DPIRD, but half the respondents considered "potentially" participating if provided with the occasion.
- Only a quarter of farmers said they were going **online to seek further** meteorological information. Some comments were gathered about already spending enough time online "looking at the weather".

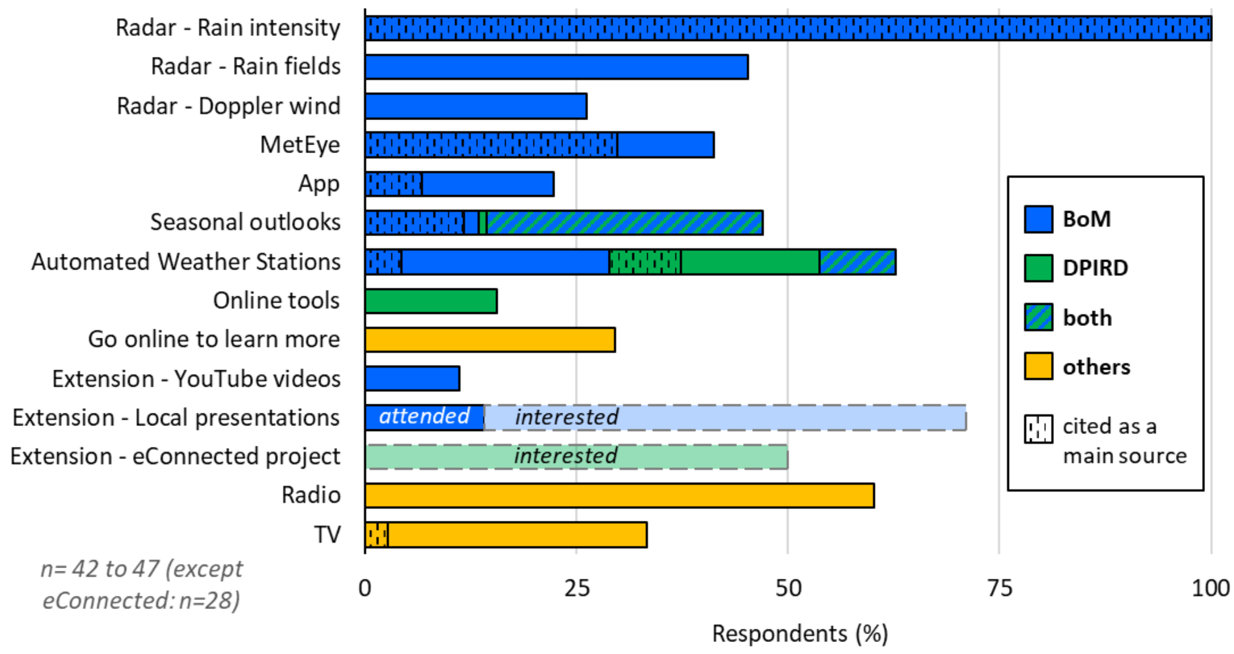



**Fig.9 Use of specific products and services.** Respondents were asked whether they used a range of products and services, even if they had not been mentioned as main sources of information earlier. For instance, MetEye represented 7% of all main sources of information (Fig.6a), and was mentioned by 30% of the respondents (Fig.6b); an additional 11% respondents mentioned actually using the product when specifically asked about it (i.e. occasionally). Similarly, the radio was never mentioned as a main source of weather and forecast information, yet almost two third of respondents listened to the weather segment on the ABC Country Hour. Note: the radar was always mentioned as a main source, but was not accessed via BoM's platforms by 21% of respondents who use third-parties instead. Responses were weighted from 0 to 1 to reflect actual use (e.g. 3 respondents using only very little a product = 1 respondent who does use it).

**There is great potential to increase the use of BoM flagship products by raising awareness of radar rainfields and wind features, or of MetEye capabilities. This can be done through increased prominence on webpages, advertisement, education. For some products (BoM's app, DPIRD tools), comments from former users suggest that design revisions and strategic re-positioning are necessary.**

**There is demand for outreach, but perhaps more for programs that have little opportunity cost for time-poor farmers. Extension via radio programs are one such option. However, online extension may not be a favourable avenue to educate farmers who already spend considerable time on computers looking at weather and forecast information.**

## Use of latest observations as indicators for spraying

Spraying pesticides is an operation that occupies a considerable amount of farmers' time, and that is highly dependent on a range of weather conditions for effective application (i.e. optimal coverage and adsorption, minimal drift and leakage). Specific questions were therefore included regarding the use of weather information to support spraying decisions. Farmers sourced the "latest observations" online from BoM's and DPIRD's networks of Automated Weather Stations, directly via the government agencies' dedicated websites (see Fig.1), or relayed by third-parties. Adding outputs from hand-held or machinery-integrated devices was also common.

These indicators were found to be very unequally used (Fig.10a). Rainfall and wind information were ubiquitously used by respondents to assist their spraying decisions. Over two-third of respondents consulted delta-T, humidity, rain 10 days, and air temperature. Other indicators were either redundant, or used only on occasion e.g. for summer spraying. On average, farmers use 8–10 indicators, depending on their emphasis on cropping (Fig.10b).

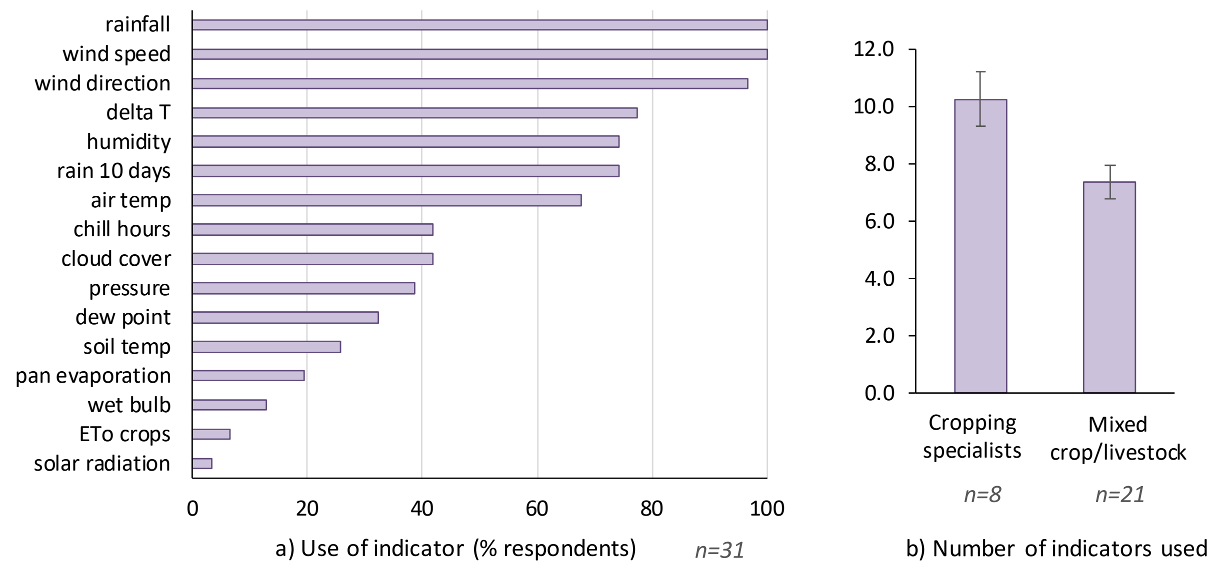



**Fig.10 Use of latest observations as indicators to inform spraying operations.** Spraying of herbicides and other pesticides occurs at seeding, during the growing season, and to a lesser extent in summer.

**The latest weather observations are important indicators for farmers, notably to support spraying decisions. However, importance varies across indicators. This should be taken into account when presenting this information online. Currently, most webpages are overloaded with information that is not prioritised.**

**New tools could be developed to enhance the use of automated weather stations outputs by broadacre farmers. For instance, dashboard apps could display only the 10 most important observations, and make others 1-click-away features. Another option would consists in allowing farmers to easily customise indicators themselves.**

# 3.3 Impacts on farming practices

- Planning: high
- Seeding: varied profiles
- Spraying: high
- Fertilising: varied profiles
- Harvest: low
- Sheep management: high

## Overview

Farmers' reliance on weather conditions and forecasts was assessed for the main practices conducted during the year which broadly include:

- **General planning** (all year)
- **Seeding**: in autumn (March-May)
- **Spraying**: mostly after seeding during the winter growing season (June-July), otherwise before seeding (April-May) and in summer (February)
- **Fertilising**: at seeding and during the growing season
- **Harvest**: start of summer (November-January)
- **Livestock management** (all year): sheep, some cattle.

This study was focused on the activities named above as, saved for rare exceptions, farmers did not consider any others to be significantly impacted by weather and forecast information (e.g. marketing, setting up insurances, preparing for storms, etc.).

Figure 11 summarises the relative impacts of the information available on each practice for:
- *near real-time i.e. monitoring current conditions* (mainly sourced from radar imagery and latest observations);
- *forecasts overall*;
- *forecast with distinct horizons* (hourly, daily, weekly); and
- *seasonal outlooks* (monthly or more).

Figure 12 provides the distribution of answers regarding the importance of the forecast overall, allowing to distinguish situations where consensus was found (i.e. majority of the population providing similar answers) or not (i.e. varied answers across the population).

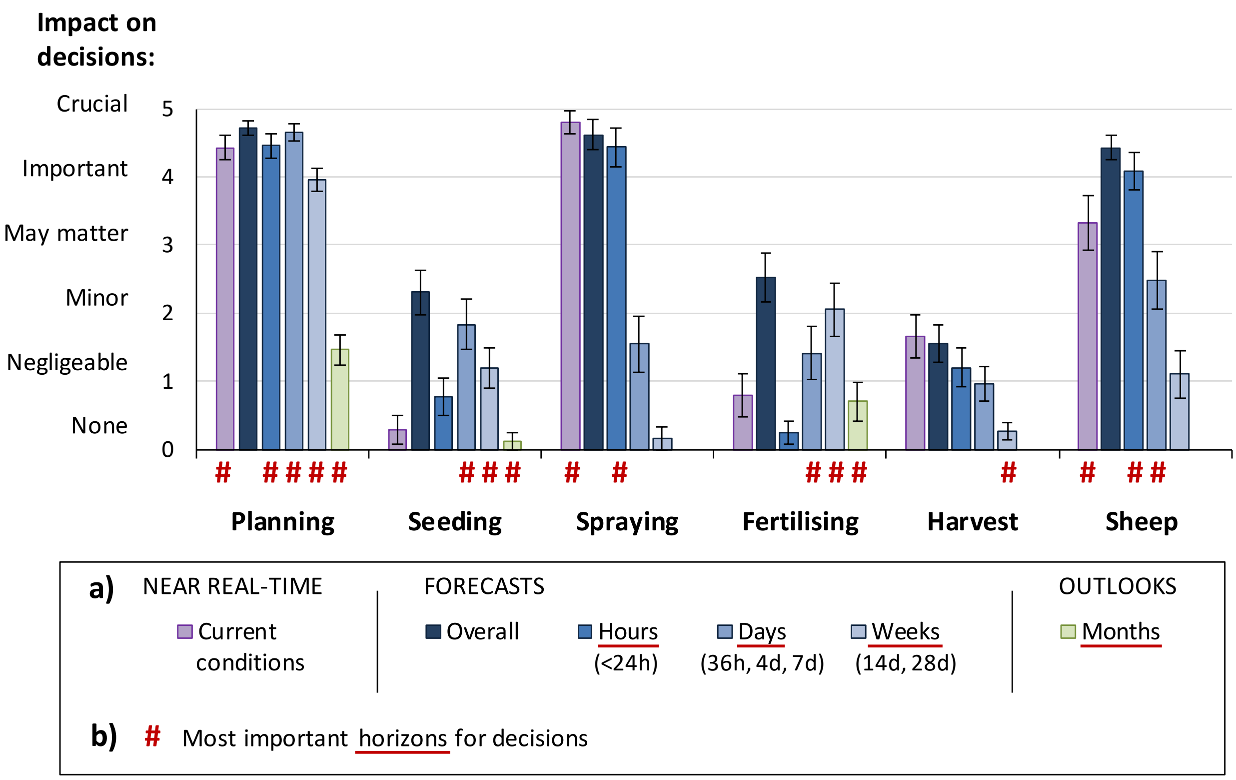



**Fig.11 Relative impacts of different weather forecasting horizons on farming practices.**
The distinction between the **actual (a)** and **potential (b)** impact of different horizons (current, forecasts, outlooks) is crucial. For instance to be able to change harvest plans, farmers require 2-week forecasts (great potential impact) which are still too unreliable (little actual impact). As a result, the impacts of forecasts on harvest decisions is limited to very short-term security matters (e.g. thunderstorms) with negligible economic impact (e.g. shutting silos for fast-approaching rain, for which weather information is not indispensable as this can be, and often is, assessed in person in the fields). The same applies to seeding and fertilising decisions for which long-term forecasts would be most important but are currently least reliable (leading other factors to override decisions for some farmers, such as logistics). The opposite occurs for spraying and sheep management, for which short-term horizons are most important, well informed, and greatly relied upon. Results are based on responses from 29-36 respondents.

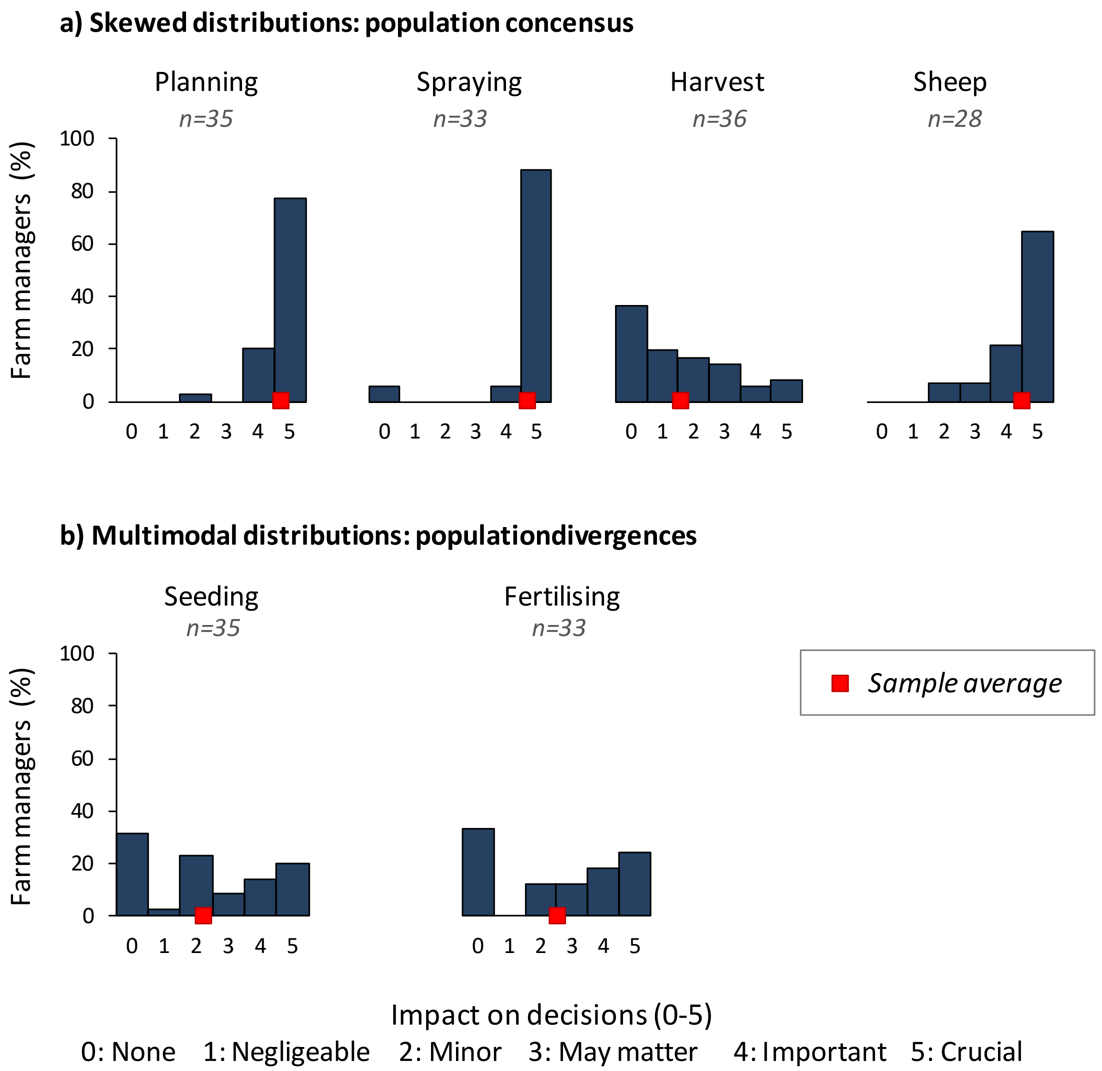



**Fig.12 Impacts of forecasts on different farming practices: distributions of farmers answers.**
This figure details the distribution of the overall forecast importance from Fig.11, limiting the answers to those of main managers. For some practices, answers were overall consensual **(a)**: forecast information is crucial for the general planning of operations, for spraying, and for managing sheep; impacts are negligible at harvest saved for safety matters. Answers diverged for seeding and fertilising **(b)**, with no clear pattern, leading to 'middle-ground' averages. It should be noted that most respondents considered the economic *scope* of forecast impact on harvest and fertiliser decisions to be negligible and relatively limited, respectively.

## Planning

Forecasts are key to planning farm strategies and operations, across all horizons (Fig.11), for all farmers (Fig.12a). Monitoring weather conditions was also considered extremely important, to alter or confirm previous plans, and adjust decisions on a daily basis.

The only horizon for which there was little attention was seasonal outlooks. Only 20% of farmers took outlooks into account for their decisions, with the majority "only looking at it" (54%) or ignoring them entirely (26%).

## Seeding

Whilst there is little doubt that monitoring the weather is always important for operating field machinery, the importance of monitoring current and seasonal conditions at seeding for this purpose was rarely ever mentioned. Changes in program (e.g. crop and land allocation) were also seldom mentioned, although a few farmers provided examples of years when it happened. At seeding, the most important decision appeared to be when to start, which typically depends on soil moisture and therefore longer-term factors. Canola is often seeded early, however decisions vary with regards to cereals. These crops constitute the core component of the program and also the most risky, due to the irregularities of autumnal rains that start the growing season in Western Australia.

The relatively low impact of forecasts recorded for the sample (Fig.11) hid important variations (Fig.12b). Three major profiles were identified depending on the importance dedicated by farmers to rainfall, past and forecasted (Fig.13).

Only a third of respondents attributed an important place to the forecast to make their seeding decisions ("wait-to-some-extent"), while the others did not base their seeding decisions on the forecast. This included one quarter of respondents who typically waited for sufficient rainfall ("trigger-based"), and over 40% of respondents who adopted the opposite strategy of early seeding for which a large proportion of the farm is usually dry sown ("pre-decided").

No factor could be identified that was typical of the two groups of farmers relying on past rainfall. However, some characteristics were strongly setting apart the sub-population of farmers who did not rely on any rainfall information: farmers with a pre-decided seeding strategy had significantly larger farms, were more oriented toward cropping, and faced greater practical constraints (Fig.13). No relationship with opinions or perceptions was identified.

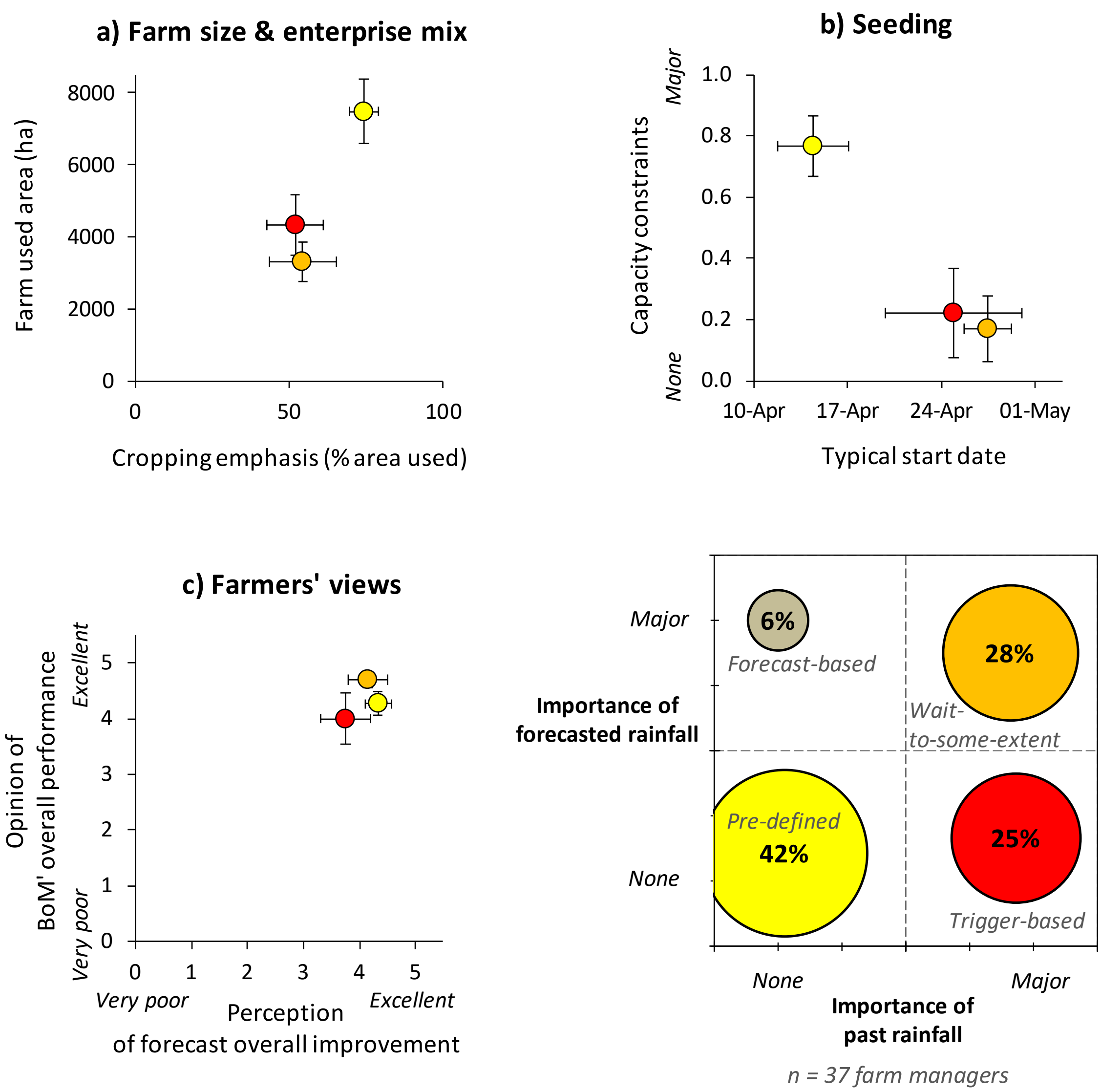



**Fig.13 Seeding profiles.** The variation of forecast impact on seeding practices was further investigated. Respondents (main managers only) were divided in four groups depending on the relative importance they dedicated to past and forecasted rainfall. Three major profiles were identified. A quarter of farmers typically wait for sufficient rainfall event before seeding. About another quarter also prefers to wait but are likely to alter their decisions depending on the forecast. The largest group was composed of farmers who entirely disconnect their seeding plan from the rainfall, actual or predicted. These farmers were significantly larger with a stronger emphasis on cropping **(a)**. They also faced stronger labour or machinery constraints and start seeding 10 days earlier **(b)**. Farmers' views about the forecast and BoM **(c)** did not appear to differ between profiles (see section 5 for more details).

## Harvest

A third of farmers reported the importance of monitoring current conditions at harvest. One reason was to avoid cold and moisture to ensure both adequate harvest of the crops and storage of the grain. The other reason, that extended to monitoring very short-term forecast, was for safety and organisation purposes: preparing for heat and wind, especially during long work days, and for thunderstones and fire risk (shutting machinery and closing silos).

In spite of this, the overall consensus was for the impact of forecasts to be negligible at harvest, due to weather-related damages not being avoidable, unless anticipated several weeks ahead. These damages included grain downgrades (staining and sprouting from rain, lodging from wind), and crop losses (frost, dry off, fire).

Two groups of farmers could nevertheless be distinguished. In spite of the low scope for preventing losses ("well under 5%" of the harvest), half the farmers said they "can" or "could potentially" reallocate their workforce or priorities depending on the forecast; the other half said nothing could be done. For each group, respectively, practical constraints to the ability to re-allocate resources were reported by 60% vs. 25% of the respondents, mostly with regards to machinery or labour capacity. Other constraints included storage limitations, logistics of far apart farms, rotations requirements, or imperatives linked to the size of the cropping program. No differences in attitude toward forecasts was found between the two groups.

## Fertiliser applications

Current weather conditions were not considered by farmers to impact fertilising decisions, except for a few respondents who mentioned the importance of monitoring rainfall location to ensure the adequate incorporation of nitrogen.

Otherwise, the impact of forecast was relatively small. Most farmers agree that both past and forecasted rainfall impact their fertilising programs, that are generally planned in advance but flexible. However, further questioning revealed that, for the most part, fertiliser plans held relatively little margin for adjustment. Many farmers do monitor the forecast and may hold on nitrogen applications (typically less than 20% variation), but the consensus is that long-range horizons would be more useful. A major factor limiting these adjustments is logistics, with most farmers having to organise, order and store large amounts of fertiliser in advance.

Beyond these results, strong divergence in answers (Fig.12b) and anecdotal evidence suggest that, similarly to seeding, different groups of farmers exist, each dedicating varied importance to rainfall and soil moisture. Investigating these profiles in more detail would require dissociating the type of application (basal at seeding, top-ups in-season), assessing the relative importance of strategies (nutrient replacement, yield potential chasing, rotation requirements), as well as determining the role of farm equipment (e.g. granule storage, liquid nitrogen) and farm-level objectives (e.g. farm enterprise mix).

## Livestock management: sheep

The weather forecast mattered to all livestock managers (greatly: 75%, to some extend 25%). Activities such as muesling, crotching, marketing and lambing were rarely mentioned. In fact, the resilience of sheep as a "tough animal that lives outside" was often highlighted, as well as the very rare weather-related losses. By contrast, 90% of respondents mentioned the importance of monitoring weather changes at shearing. In these rare instances when sheep may be particularly vulnerable, or that conditions are particularly adverse for workers, activities are re-scheduled or if unavoidable, shelter is sought after (keeping animals in the shed or pushing mobs in bushy areas).

Similarly, all respondents reported the importance of 1-day to 1-week forecast to plan and organise an enterprise that mostly consists of unsheltered outdoor activities. Many respondents also monitor current conditions in the case of fast-approaching cold snaps or thunderstorms, although some said not needing internet-based products for observations that could be made directly in paddocks on a per-need basis.

**Generally, weather and forecast information is of great importance to farming, especially during planning phases. However, not all practices are impacted to the same extent. Spraying and sheep management rely heavily on short-term forecasts. Practices which decisions require longer-term horizons, such as seeding, fertilising, and harvest are much less impacted by the current available forecasts.**

**Important variations exist within the farming population, notably for seeding. An implication is that forecast improvements are unlikely to impact the businesses which strategies are largely disregarding forecasts (half the population, who are either dry seeding or waiting for sufficient rainfall).**

# 3.4 Farmers' views

- Confidence in forecasts: high
- Opinion of BoM: high
- Skill perceptions: realistic
- Current gaps: few

## Overview

Opinions regarding BoM showed little variation across the sample with the vast majority of respondents demonstrating great confidence in BoM's performance, both in terms of overall competences (high and very high: 81%) and overall improvement in forecast skills during the past few years (high and very high: 71%). This corroborated previous results about the overall great importance of weather and forecast information to farmers.

General questions were asked to farmers to assess their views, as a means to:

- explain some of the previous observations
- estimate the population's sentiments about the current level of weather services
- provide the opportunity for respondents to voice their opinions, notably regarding areas deserving of future investments.

## Confidence, opinions and perceptions

Confidence in forecasts decreased with horizons lengths (Fig.14a). **Confidence was very high up to 4 days** and low after 10 days, corroborating observations regarding impacts on practices (general correlation with forecast needs and performance). Greater variation in opinions for longer horizons can be noted (standard errors increase with longer horizons).

Questions about BoM and overall forecast improvements **were very positive**. Over 80% of respondents considered BoM's performance and competence to be very good or excellent (Fig.14b), and nearly three quarters thought forecasts had greatly improved over the years (Fig.14c).

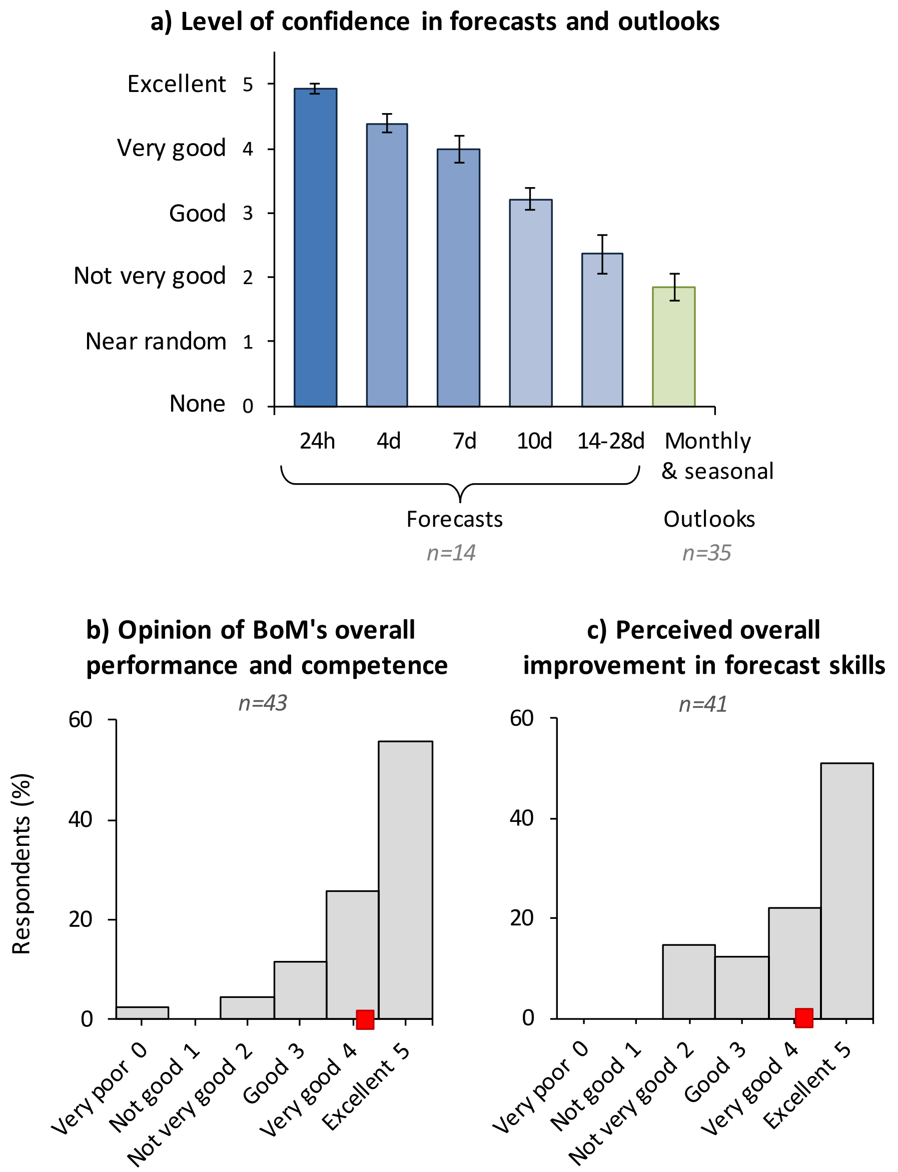



**Fig.14 Farmers' views in relation to weather forecasts.** Bars are standard errors around the mean (**a**), and the red squares indicate sample averages (**b** and **c**).

## Perceived gaps

Farmers were asked where they considered gaps to still exist in terms of information and services related to weather and forecasts, i.e. where they thought future investments should focus. The **most common answer was that the current level of services was, in facts, already excellent** (Fig.15). Otherwise, the most common request was for improved forecast performance, although most respondents acknowledged the difficulty of achieving greater skill. Apart from this, there was little consensus on the gaps to potentially fulfil. Most indicated improving tools that are already available (e.g. ease of use, alert features). Some farmers suggested further technology deployment to increase radar and station coverage, and perhaps adding moisture probes to the network.

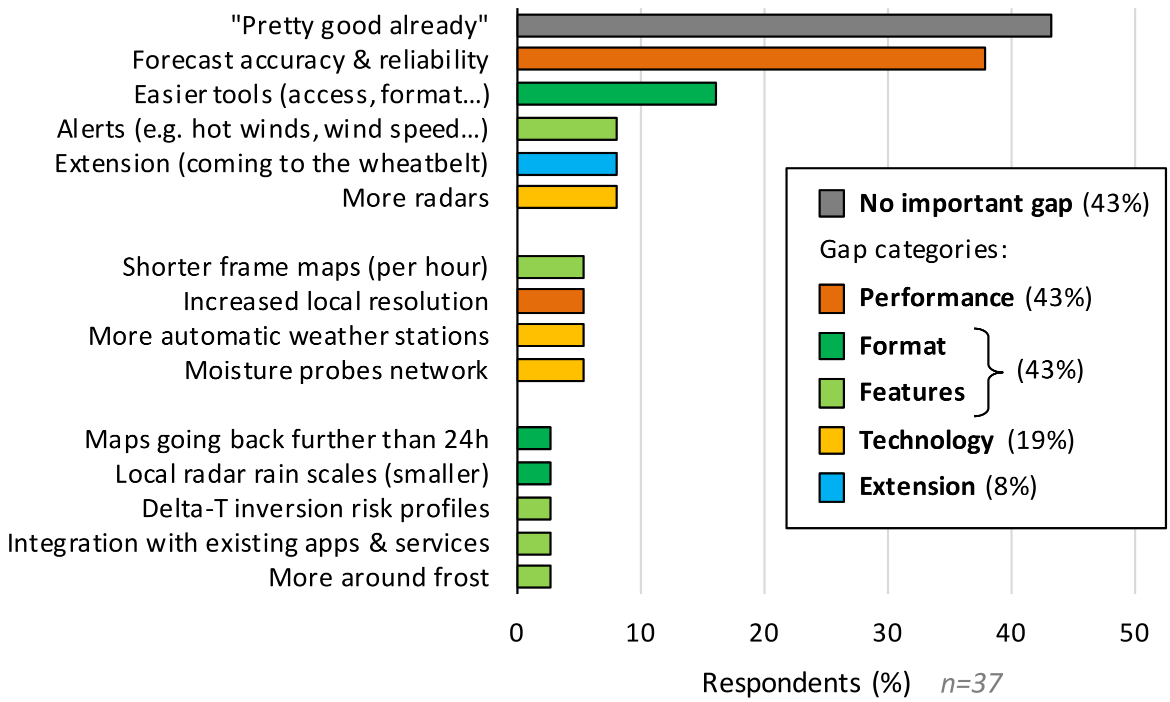



**Fig.15 Current gaps in meteorological products and services according to farmers.** Each respondents nominated 1–3 gaps. A majority considered the information currently available to be very good.

**Although greater forecasting accuracy is always hoped for, especially for longer-term forecasts, most farmers have realistic expectations and are generally very satisfied with BoM's outputs.**
**Therefore, and since radar coverage had just been completed, farmers think that current efforts should continue and do not consider other meteorological investments to be a priority, saved perhaps for refining existing products and continuing to develop the rural data collection network.**

# 4. Conclusions

## Conclusions

This study is the first to investigate in detail the use of available weather and forecast information by broadacre crop and livestock farmers in Australia. Representative data was accessed first-hand from farming businesses in the Western Australian wheatbelt to document which products farmers use as main sources and what characteristics are valued in these products, as well as to provide a quantification of the relative impact of different forecast horizons on a range of practices.

The results have direct implications for future investments in Australia, notably to improve the strategic delivery of this information. Results also provide a baseline to evaluate the potential impact of improved weather and forecast information. Different horizons (near real-time monitoring, short and long-range forecasts, seasonal outlooks) have varied impacts on farming practices, and the potential for improvements varies as well.

The results of this study are significant beyond Australia, notably for the numerous modelling studies that assess potential agricultural benefits from improved forecast information. This study demonstrated that models must take into account the varied (and sometimes limited) scopes for improvements that exist to impact given practices, as well as the heterogeneity that may exist within farming populations. In that regard, the importance of pragmatic farm constraints was highlighted: whilst weather and forecast information are an integral part of broadacre farming in Australia, some practices that were consensually thought to be highly dependent from the forecast appear disconnected from the weather for an important proportion of businesses. This was demonstrated to be the case for the timing of seeding, with further investigation warranted with regards to fertiliser applications. This study provided a first account that future research efforts can build upon.

# Appendix

## A: Participant Information Form

## B: Interview guidelines

# APPENDIX A - PARTICIPANT INFORMATION FORM

THE UNIVERSITY OF WESTERN AUSTRALIA

**Myrtille Lacoste**
School of Agriculture & Environment, M089
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
M 04 48 68 49 01 / 0434 666 195
E myrtille.lacoste@uwa.edu.au
www.are.uwa.edu.au

1st June 2017

## Estimating the benefits from Doppler radar investments in the WA wheatbelt

Dear Sir or Madam,

Thank you for participating in this study. **Your time and your efforts are greatly appreciated.** Although participation is entirely voluntary, before confirming your consent you do need to be aware of the following information.

### Aim of the study

This survey is part of an independent study by UWA, funded by the Bureau of Meteorology, to estimate the benefits (financial and non-financial) from Doppler radar investments in the WA wheatbelt (Royalties for Regions). To do this, this project will investigate **how farmers and other community members use weather-related information**. This includes existing products and services from BoM, DAFWA and other sources, and new ones resulting from the Doppler radars recently installed in Newdegate, Doodlakine and Watheroo.

To do this, you will be asked a variety of questions about the farm and how you work on it. The project is carried out by myself and overseen by Dr. Marit Kragt.

### Possible benefits

**The main reason to conduct this study is to benefit the wheatbelt region** by providing funding bodies and policy makers with better information to inform future investments in related technologies and outreach efforts.

**You will receive a summary of results**, and learn what are the practices of other farm businesses in the region.

**More broadly**, that information will also help to increase knowledge about agricultural and rural practices, for instance to improve agricultural models. This will help inform research and extension efforts beyond Western Australia.

## How was I selected and what does participation involve?

Farmhouses are selected at random using satellite images from Google Earth, public cadastral maps, driving around the study area, and following the recommendations of previous participants.

Depending on how much time you have and on how much information was already collected, the interview will last between 15-45 minutes. *Please feel free to interrupt the interview at any time or to re-schedule.* There may be some follow up later, usually no more than a few clarifying questions.

## Privacy, voluntary participation, withdrawal

**All the information provided will be treated as strictly anonymous and confidential**. This includes your identity, all identifiable information, and the detail of your responses. The data will only be handled by myself, and coded in a de-identified format to protect your privacy. No one else will know that you participated in this study, and it will not be possible to identify individual respondents from the results presented. *Please note: the only exception to this principle of confidentiality is if documents are required by law, however it is not the objective nor role of this study to monitor or disclose legal requirements.*

**Participation is voluntary.** You can also **withdraw from the study at any time**, without giving an explanation and without consequences. If you wish to withdraw, the data will be destroyed unless you specify otherwise.

## Consent form

If you are comfortable with this information in mind, please sign the Participant Consent Form to confirm your consent to participate in this study. *You are welcome to retain a copy of these documents for your records.*

## Contacts

There are no foreseeable risks associated with the research. Nevertheless, **if you have questions or concerns** or simply if you would like to discuss any aspect of this study, please feel free to contact me (0434 666 195), Dr. Marit Kragt (04 06 588 64), or the Ethics Committee of UWA (details below).

Sincerely,

Myrtille Lacoste
Project Investigator

*Approval to conduct this research has been provided by the University of Western Australia with reference number RA/4/1/9051, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.*

*In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics office at UWA on (08) 6488 4703 or by emailing to humanethics@uwa.edu.au.*

*All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.*

# APPENDIX B - INTERVIEW GUIDELINES

/ 10 /2017
start → end

## FARM

● **Land:** ___________ **total ha** **Sheep:** _________ **rep. ewes**

___________ **arable ha** Cropping: ___________

non arable used:

● **Who works on the farm (FTE):** Manager: Wife: Parents: Employees:

= **FTE / needed permanent workers**

● **Machinery in use**: **Seeder:** _________'' **Harvester:** _________''

Renewal strategy: Kept for: ≈ ______ yrs ≈ ______ yrs

●**Age:** ________ Mgmt emphasis:

## TECH

**Coverage** mobile phone: % paddocks

**Computer & tech reliance:**

- most / all office work
- that collect field data? machinery: inputs? yield mapping? **use it?** yes / no
- moisture probes? network or cloud setup ?

**- interested in all that?** not really yes – maybe in the future / definitely

# WEATHER & CLIMATE INFO, FORECASTS, TOOLS…

**If you think about all that is available, what do you use?**

**Why those and not others?**

**How often looks at weather?**

**- MetEye?** **- BoM app?** **- Radio?** **- TV?**

**- BoM YouTube videos?** **- been to a BoM prez?** **- Interested?**

**- Seasonal outlook :** Ignore it look at it: **BoM / DAFWA**

**● DAFWA online tools ?** **Why?** **- Heard of eConnected?** **interested?**

**● AWS BoM / DAFWA : look at data online on website?** yes /no via others only

**● NEW RADAR** **loop: rain rates (intensity)** **rainfall (mm)?** **Doppler wind**

6 min 1h since 9am 24h

another link at the top-right side

**- Changed anything practically?**

**- Has it changed how your overall confidence in these short-term forecasts? (decreased risk?)**

**- What/how did you do/use BEFORE the radar?**

## PRACTICES

- **Seeding** **Shifts: ________** **Start:**

- **Stretching it with current capacity?** No – yes: land labour machinery

- **Seeding plan: how makes decision to start?**

→ Pre-defined plan / **Trigger point = wait for certain amount of rain?**

→ Does the forecast matter?

- **Has the radar helped?** how? (Changes/improvement in decision point?)

- **Harvest**

- **weather-related losses (or others)**, that **forecast can help with?**

- **Anything can do about it at all?** eg labour allocation? work quicker for if wet front coming?)

- **will the radar help at all?**

- **ALL Spraying**

- **total spendings ha on crops** = _________$/ha

- eg conditions turn poor → % farm mis-applied? __________

% farm has to re-spray? ________

→ if not, yield loss?________

→ loss a tank of chemicals?________

- **INDICATORS →**

**LATEST OBS**
rainfall
rain 10 days
cloud cover
wind speed
wind direction
delta T
dew point
EP air
wet bulb
pan evaporation
chill hours
solar radiation
soil temp
air temp
humidity
pressure
ETo short/tall crop
Richardson Chill u.

● ALL **Fertiliser adjustments/ yield pot**

**Basal rate , Top-up later ….**

- **How these ferti decisions made?** → Pre-decided depend on past weather ?

→ forecast dependent?

→ **Is the radar making/will make a diff? if yes how so? - What would help more?**

● **Sheep: massive implications of weather forecasts?**

- moving animals
- selling quicker if dry spell

→ **Is the radar helping at all?**

● **Can think of any other weather-related losses, avoidable, in last few years?? ($)**
**can do something about it**

● **What would YOU invest in? / what is missing/to do next? Gaps?**

Radar technology
Extension/presentations
Weather stations
Decision Support Tools, models…
Reports/Newsletters

● **Read online about El Nino, interpreting weather data, etc. for your own interest? y / n**

● **FORECAST PERFORMANCE OVERALL: your own impression: do you think it has improved along the years?**

email:

THE UNIVERSITY OF WESTERN AUSTRALIA
School of Agriculture and Environment