Australia's National
Science Agency

Understanding grower attitudes to digital technology

Final Report

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Acknowledgments

Project funding was provided through a Collaboration Agreement for the provision of services to the Agricultural Innovation Hubs Program between the Grower Group Alliance (GGA) and the Liebe Group. The purpose behind the GGA grant is to increase the uptake of innovation by producers, stimulate collaboration in the agricultural innovation systems and increase commercialisation outcomes.

Executive summary

The Liebe and Stirling's to Coast (STC) grower groups combined with CSIRO to evaluate modern digital technologies with dryland grain farmers. Technologies evaluated included weather stations, weather apps, yield maps generated by grain harvesters, soil water probes installed on farm, crop simulation models and satellite imagery transformed into NDVI maps of cropping fields. Each technology was provided to growers, who were subsequently surveyed about their opinions relating to technology. A workshop with each grower group was conducted in Albany and in Dalwallinu, Western Australia, to enable group discussions about technology.

The key finding was that growers adopt technology, and are willing to try new concepts. On average, growers used 7 different pieces of digital technology. Weather information, and climate forecasts were the most sought after. Information relating to crop yield and soil moisture were widely used. However, data integration, data assimilation and data interpretation were often problematic. A wide range of industry platforms were used by growers, and there was frustration that often technology was not supported, and growers had to engage with technology through multiple different platforms. Ideally, growers would like technology to be better supported by advisory networks to ensure it provides them with information when it is needed.

Technology with clear uses, such as weather and the Delta T information that informed spraying was most highly valued. As the application and purpose of technology become more abstract, then the perceived usefulness of the technology declined. For example, earth observation technology, such as NDVI, was considered interesting, but the management action related to this technology was difficult to discern.

Workshop discussions revealed that growers were most interested in technology that helped with a critical management decision. This invariably meant a technology should assist with an action related to crop planting, crop nutrition, soil amelioration, weed detection and management, pest detection and management and pathogen detection and management. Growers were also interested in how technology could boost economic returns. That is, growers would rapidly adopt technology with a clear use case, and an obvious value proposition. Many of the existing technologies do not quite provide a clear use case or a clear value proposition. Despite this limitation, growers were willing to try technology to help identify these use cases and values. Future products should endeavour to clearly define these components, and if they do, are likely to be rapidly adopted.

1 Introduction

Australian grain growers have had access to multiple forms of digital technology for more than 20 years. This technology varies and can include items such as yield maps measured by grain yield monitors attached to grain harvesters, satellite imagery that produces a map of the Normalised Difference Vegetation Index (NDVI) of the field (Colaço et al. 2021), in-situ soil moisture sensors attached to data loggers that provide information about soil moisture down the soil profile (Bramley and Ouzman 2019), and IoT connected weather stations that provide near real time insights about rainfall, temperature and windspeed (Jayaraman et al. 2016). Other technology has been created to help farmers define soil types with electromagnetic and gamma-radiometric soil surveys (Wong and Lawes 2012).

These digital technologies theoretically enable IoT connected Smart Farms to operate, where data about the prevailing agro-environment are delivered to the farmer, via various mobile devices (Jayaraman et al. 2016). A review of IoT Smart Farms identified that insights from these sensors could then be used in application domains such as monitoring, control, logistics and prediction (Talavera et al. 2017). For example, the farmer may use the IoT devices to monitor fields, control machinery, manage the logistics of operations or predict the final yield of a field.

However, the adoption of complex digital technology by farmers is mixed, even though, at a superficial level the technology appears tantalisingly useful to grain farmers. In a recent survey of Australian grain growers (Bramley and Ouzman 2019) identified that 84% have adopted controlled traffic, 57% of farmers produce a yield map, 40% have used satellite imagery, 37% have generated high resolution soil surveys with digital technology, 23% used soil moisture sensors and just 12% had used proximal sensing. Decision support systems (DSS) for nitrogen fertiliser decision making, such as Yield Prophet (Hochman et al. 2009) were used by 26% of growers. Therefore, the adoption of digital technology varies between farmers and between the type of digital technology.

The exploration about the uptake of digital technology is not new. In an Australian context, (Robertson et al. 2012) first identified that the uptake of variable rate technology, a component of precision agriculture was just 20%, and larger farms were more likely to adopt. Technological complexity contributed to the lack of uptake. However, the more recent study by (Bramley and Ouzman 2019) demonstrated that farm size was no-longer an important discriminator of uptake in digital technology more generally, while technological complexity was still a factor. Both studies acknowledge the role that technology service providers and agricultural consultants play in facilitating the use and uptake of digital technology.

No published study about Australia agricultural consultants, and their attitudes to digital agricultural technology could be found. However, in Ontario, Canada 96% of agricultural consultants reported the use of some form of precision agriculture as part of their agricultural consulting business operations. The nature of the precision agriculture technology offering varied although technologies such as zone-based soil sampling, guidance technology and variable rate fertiliser strategies were deployed by at least 70% of the consultants surveyed. Interestingly, the most widely adopted technologies by the consultants, were also deemed the most profitable to the consulting business. However, consultants noted that the provision of digital technologies to farmers was not always a profitable venture, given farmers willingness to pay (Mitchell et al. 2018). The cost structures of Australian consulting businesses, regarding the supply of digital technology is unknown. However Australian growers have reported that they are concerned that service providers may not be available to provide ongoing support (Marshall et al. 2022), which could imply that the business stability of these consulting and service providing operations is not particularly viable, yet the role on consultants in an Australian context is vitally important.

Grower attitudes to technology are influenced by factors beyond the use and delivery of the technology. Researchers have identified that underlying farmer trust in digital technology and big data are important factors that influence growers willingness to consider these technology offerings (Fleming et al. 2018).

More generally, the adoption of technology is driven by a multitude of factors. Underlying technology acceptance models (TAMs), that relate to theories around planned behaviour, provide some context to why technology may, or may not be adopted by individuals (Pierpaoli et al. 2013). Along with the usual variables about demographics and enterprise scale, these TAMs point to the importance that perceived useability (PU) and the perceived ease of use (PEU) contribute to uptake. (Pierpaoli et al. 2013) defines perceived useability as "the degree to which a person believes that using a particular system would enhance his or her job performance" and perceived ease of use "the degree to which a person believes that using a particular system would be free of effort".

Such frameworks provide a mechanism to evaluate how growers perceive technology, and this project was established to better understand how growers use digital technology, what they use the technology for, and what may encourage them to use more technology in their farming businesses. To that end, we provided technology to farmers, conducted a group workshop and performed farm surveys to better comprehend grain farmer attitudes to the adoption of digital technology.

2 Methods

2.1 Digital Technology

Technology was provided to, or sought from, farmers over the course of the project. The technology considered in this project included:

2.1.1 Yield Maps

Yield maps, generated by yield monitors attached to GPS located combine harvesters were created, interpreted and visualised in proprietary software. Software used for display included CNH, John Deere, PCT Ag and SMS Ag.

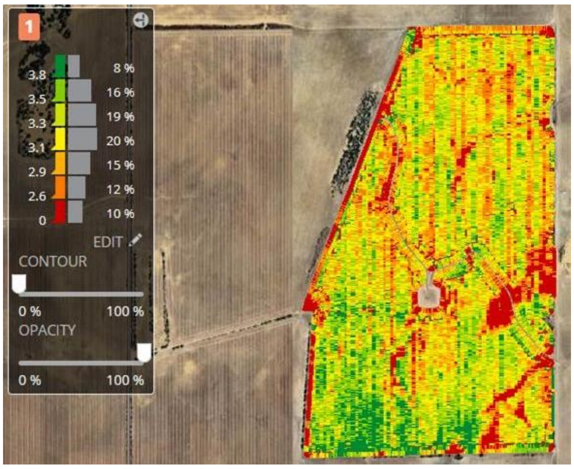


Figure 1 An example of a yield map, generated in the John Deere Operations Centre of a famer's wheat field in 2022.

2.1.2 Satellite Imagery and NDVI

NDVI maps of the fields where yield maps were generated. NDVI was captured using Sentinel-2 imagery and processed in Google Earth Engine. The entire field's NDVI was capture in September. The mean field NDVI was monitored through the growing season, using a combination of Landsat 8, and Landsat 9, Sentinel-2 and MODIS satellites. A time series of the mean NDVI of the field was created. An identical image was created for the previous season to allow growers to evaluate the growth and development of a crop from 2 consecutive seasons.

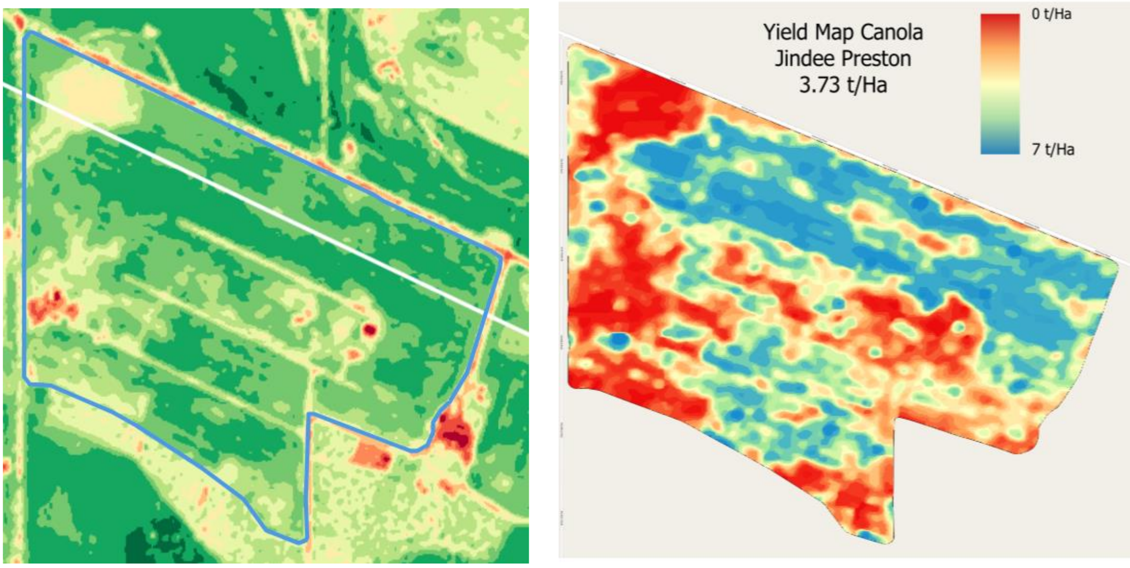


Figure 2 NDVI image captured from sentinel 2 imagery in September for a Canola crop, and the resulting, final yield map for comparison

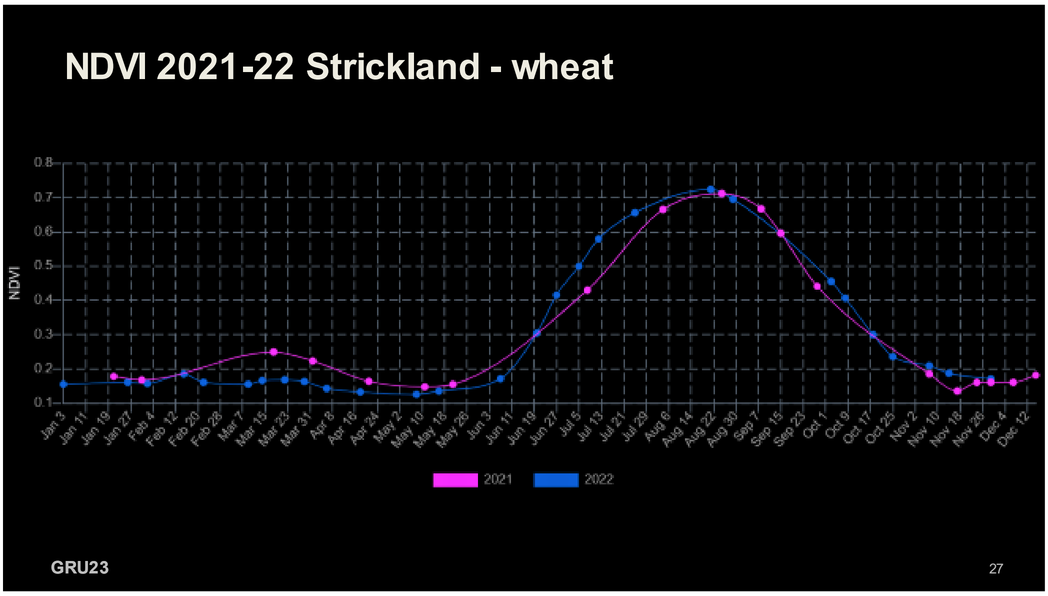
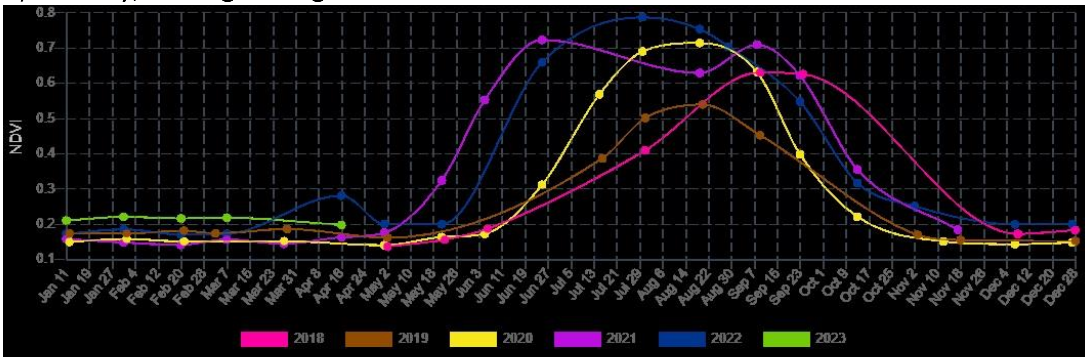


Figure 3 NDVI time series, produced from multiple Satellite platforms for the 2021 and 2022 growing season.

a) Barley, 2022 growing season



b) Canola, 2022 growing season

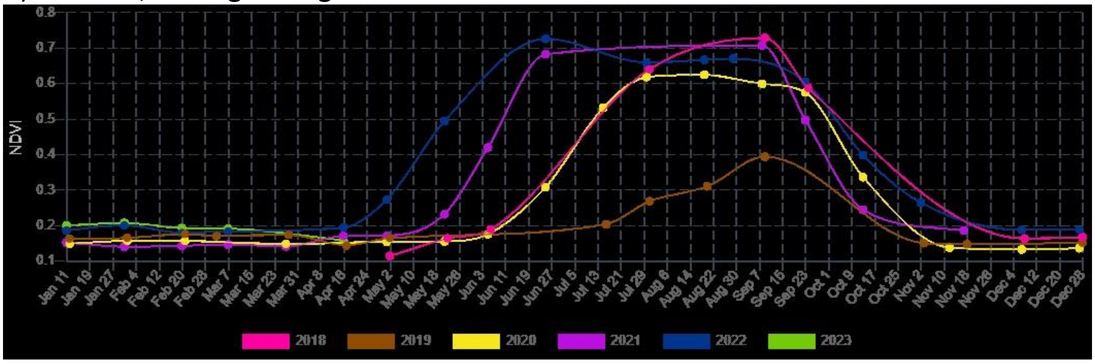


Figure 4 NDVI time series, produced from adjacent paddocks (a=barley; b=canola) using the Sentinel-2 platforms for the 2018 to 2022 growing seasons.

2.1.3 APSIM crop modelling and Yield Prophet$^{tm.}$

The crop model was calibrated from soil data from the field, and simulations were conducted using SILO data to predict crop yield performance during the season. Probabilistic estimates of the N requirement were also generated and presented to growers as a cumulative probability density function.

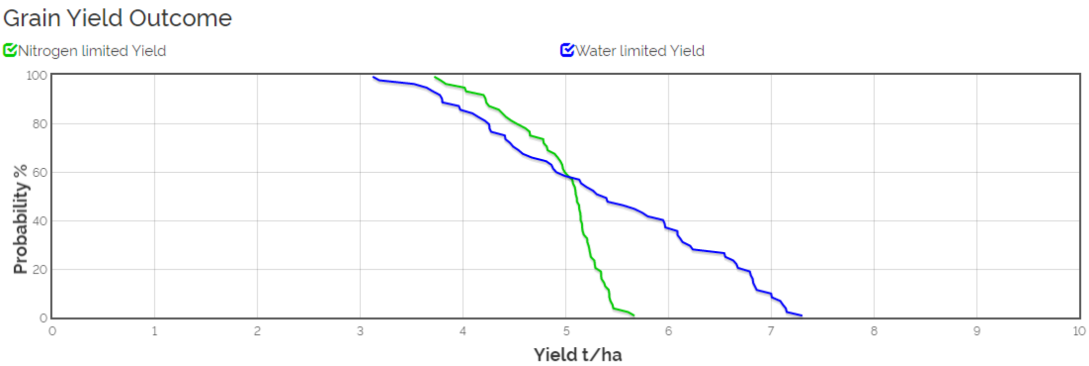
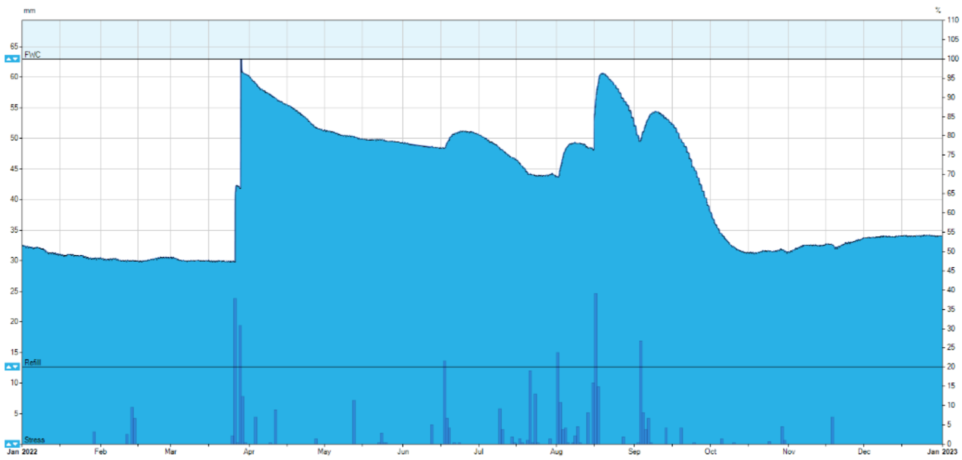


Figure 5 An example of cumulative probability output from the APSIM crop model, via Yield Prophet.

2.1.4 Soil moisture data

Soil moisture data was collected via soil probes installed to a depth of 1m in each of the fields. The soil moisture probes were installed as an IoT connected device, to provide farmers with daily updates about the soil moisture status. Data from the soil moisture probe was post processed to provide estimates of the drained upper limit (maximum amount of soil water) and the crop lower limit (minimum amount of soil water the crop can access).

a)



b)

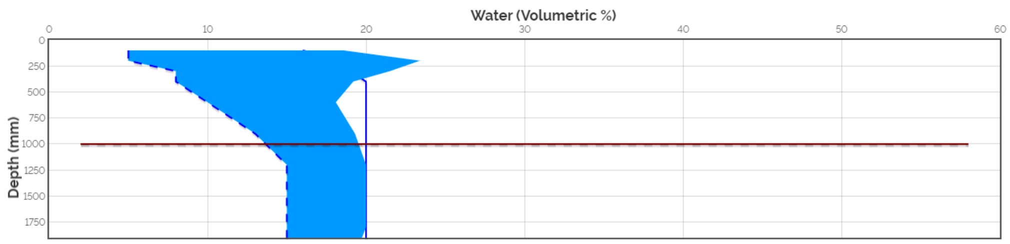


Figure 6 a) Soil moisture, from a single probe, with data displayed as a time series. b) Soil water displayed as a volumetric property for the entire profile at a single point in time.

2.1.5 Weather data

Weather data, from a nearby weather station was presented to the growers in the form of delta T, that relates to conditions that suit farm operations such as spraying.

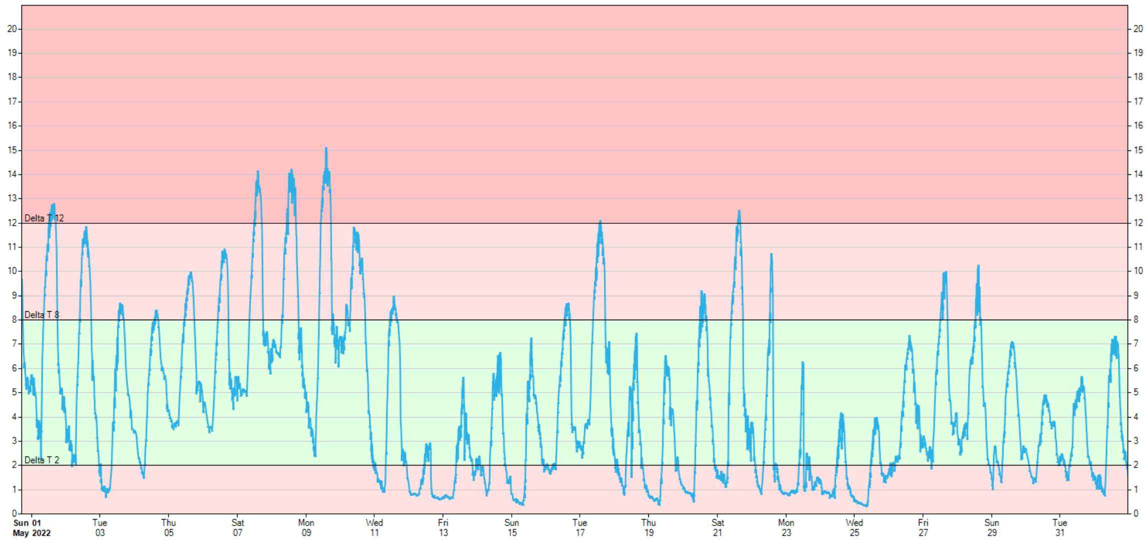


Figure 7 Output from a weather station, converted to provide insights into delta T, required for spraying.

Delta-T provides a useful tool for informing decisions about the spraying of agricultural crops. By using Delta-T values, farmers and agronomists can determine the appropriate spraying conditions to optimize the efficacy of herbicides and minimize the risk of spray drift.

Delta-T is a measure of atmospheric stability that consider the standardised relationship between temperature, relative humidity and spray droplet life and provides an indication of water evaporation rate and reveals how optimal current conditions are for droplet life.

Delta-T is calculated using measurements of temperature and humidity. The formula for calculating Delta-T is (T - Td)/2, where T is the air temperature in degrees Celsius, and Td is the dew point temperature in degrees Celsius.

Higher Delta-T values indicate unstable atmospheric conditions, which can lead to spray drift and reduced efficacy of herbicides. Lower Delta-T values indicate more stable atmospheric conditions, which are more suitable for spraying. From Figure 7, ideal spray conditions fall in the range from 2 to 8, for the ranges of 0-2 and 8-12 spray activities should be considered with caution and above 12, no spraying should be carried out and presented in table 1.

Table 1 Outputs from the spraywise decision guide about interpreting Delta T

Spray Planner Notation		Spray Quality – Delta T (^{o}C)	
Spray Action	**Symbol**	**Medium or Finer**	**Coarse or Greater**
Go		Between 2 and 8	Between 2 and 8
Caution		0 - 2 or 8 - 12	0 - 2 or 8 - 12
Stop		Greater than 10	Greater than 12

Source: Spraywisedecisions.com.au

Delta-T can also be used to determine the appropriate nozzle type and spray volume for different spraying conditions. For example, in stable conditions with low Delta-T values, low volume spraying with a fine mist nozzle can be used. In unstable conditions with high Delta-T values, high volume spraying with a coarse droplet nozzle is more appropriate.
It is important to note that operators need to additionally factor wind conditions into their spraying decision making.

Systems like https://www.spraywisedecisions.com.au can provide an integrated package of information to implement of Delta-T.

2.1.6 Additional Crop Simulation and Economic Insights

Additional APSIM simulations, that demonstrated alternative time of sowing, nitrogen fertiliser and cultivar decisions for locations was created to illustrate how APSIM could be used in a more complex manner than provided in Yield Prophet.

Cultivar	Sowing Date	Additional Fertiliser	Harvest Date	Yield	N response
Trojan	22-Apr	0	3-Nov	2372.8	
		32.5	3-Nov	3171.3	799
		65	3-Nov	3974.3	1602
Trojan	22-May	0	22-Nov	2409.2	
		32.5	22-Nov	3361.6	952
		65	22-Nov	3988.9	1580
Trojan	22-Jun	0	8-Dec	1967.8	
		32.5	8-Dec	2319.4	352
		65	8-Dec	2585.1	617
Scepter	22-Apr	0	24-Oct	2431.8	
		32.5	24-Oct	3178.2	746
		65	24-Oct	3989.1	1557
Scepter	22-May	0	18-Nov	2399.4	
		32.5	18-Nov	3404.0	1005
		65	18-Nov	4203.4	1804
Scepter	22-Jun	0	6-Dec	2056.4	
		32.5	6-Dec	2504.5	448
		65	6-Dec	2993.0	937
Wyalkatchem	22-Apr	0	15-Oct	2556.8	
		32.5	15-Oct	3251.1	694
		65	15-Oct	3542.1	985
Wyalkatchem	22-May	0	12-Nov	2460.2	
		32.5	12-Nov	3384.3	924
		65	12-Nov	4303.6	1843
Wyalkatchem	22-Jun	0	3-Dec	2141.3	
		32.5	3-Dec	2504.3	363
		65	3-Dec	3003.5	862

Figure 8 Summary outputs from an APSIM simulation of a wheat crop, evaluating three cultivars x three sowing dates and 3 fertilizer rates.

Row highlighted in orange represents the farmer's actual management practices and the paddock yield based on yield map analysis was 3.1 t/ha.

Parameters predicted with a daily step in this 2022 simulation included: ExtractableSoilWater, PlantAvailableWater, SoilAmmonium, SoilNitrate, Wheat.AboveGround.N, Wheat.AboveGround.Wt, Wheat.Grain.Number, Wheat.Grain.Protein, Wheat.Grain.Size, Wheat.Grain.Total.N, Wheat.Grain.Total.Wt, Wheat.Phenology.CurrentStageName, Wheat.Phenology.Zadok.Stage, Wheat.Total.Wt, WheatNitrogenStressFn, WheatWaterStressFw and Yield.

Additional gross margin analysis of a field was presented to growers to illustrate how farm financial data can be paired with information from yield maps to create field gross margins.

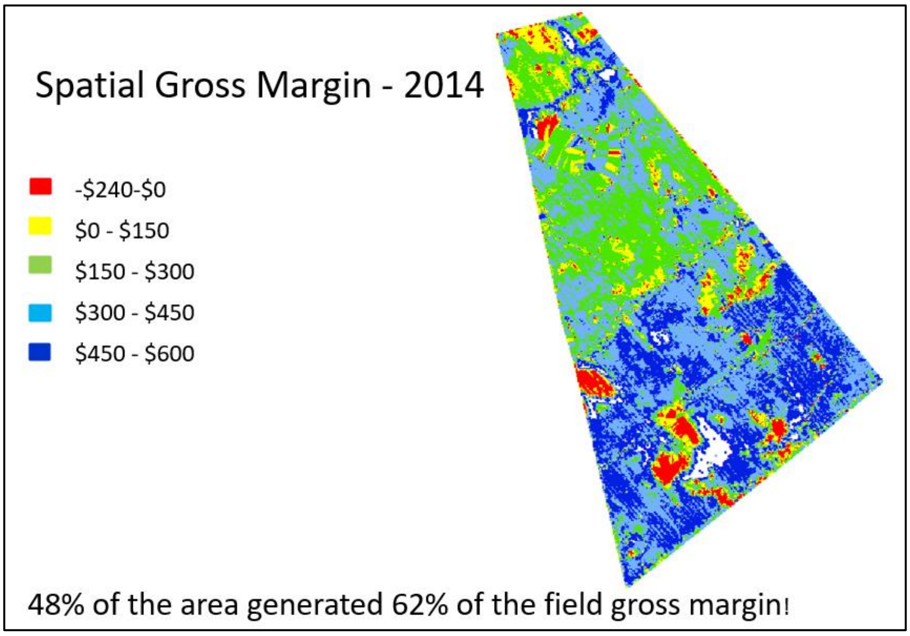


Figure 9 Example of a spatial gross margin analysis derived from a yield map

The transformation of yield maps into gross margin maps for economic analysis was seen as introducing further complexities, beyond those indicated above for general yield maps. However, 90% of Liebe and 50% of STCF are currently using AgriMaster or Xero software presumably capable of generating gross margin analysis at the paddock level which could then be used to generate gross margin maps.

2.1.7 Data collection from Trial participants

Data from 19 fields were collated, (1-14 Liebe Group and 15-18 STCF) as part of the project. Brief descriptions of each field, the appropriate APSIM soil classification, crop grown, and cultivar are provided in table 2.

Table 2. Locality and size of the test paddocks, soil type description, crop type and cultivars sown in 2022 by the Liebe Group participants and Stirlings to Coast participants

Pdk_ID	Locality	Paddock size (ha)	Crop Type	Crop Cultivar	Yield prophet Soil description
1	Dalwallinu	218	Barley	Planet	Duplex Sandy Gravel (Buntine No143)_Liebe Group
2	Jibberding	193	Wheat	Vixen	Duplex Sandy Gravel (Buntine No24)_LiebeGroup1
3	Dalwallinu	176	Wheat	Ninja	Acid Yellow Sandy Earth (Buntine No435)_LiebeGroup1
4	Bunjil	154	Canola	Garrison Xc	Duplex Sandy Gravel (Buntine No143)
4.1	Bunjil	191	Barley	Buff	Duplex Sandy Gravel (Buntine No143)
5	Buntine	119	Wheat	Mace	Duplex Sandy Gravel (Buntine No24)_LiebeGroup1_LiebeGroup2

6	Xantippe	87	Wheat	Sceptre	Duplex Sandy Gravel (Buntine No24)_Liebe Group
7	Buntine	158	Wheat	Calibre	Duplex Sandy Gravel (Buntine No24)_LiebeGroup1
8	Ballidu	162	Wheat	Vixen	Deep loamy duplex (Buntine No430)_Liebe Group
9	Latham	100	Canola	Emu	Acid Yellow Sandy Earth (Buntine No435)_Liebe Group
10	Maya	180	Canola	Emu	Duplex Sandy Gravel (Buntine No143)_Liebe Group
11	Marchagee	352	Canola	4022P	Yellow sand over gravel (Jibberding No955)
12	Watheroo	97	Canola	Emu	Red-brown Non-Cracking Clay (Yandanooka No446)_Liebe Group
13	Perenjori	52	Wheat	Devil	Duplex Sandy Gravel (Buntine No143)_Liebe Group
14	West Pithara	61	Wheat	Vixen	Brown Clay (Perenjori No830)_Liebe Group
15	Woogenellup	176	Wheat	Scepter	Sandy Loam over Clay[#]
16	Woogenellup	188	Canola	45Y28	Sandy Loam over Clay[#]
17	Mount Barker	39	Wheat	Illabo	Sandy Loam over Clay[#]
18	Cranbrook	107	Canola	45Y28	Sandy Loam over Clay[#]

[#]Source: https://www.asris.csiro.au/ASRISApi#/ as Yield Prophet was not used by STCF.

There wasn't a great difference in average paddock size between the groups, Liebe group was 153 ha, while for STCF it was 127.5 ha, suggesting that there should only be a small difference in "adopters of PA and economics of scale" between the groups. This finding relates to field size, not farm size. The perception during the two workshops was that Liebe was further along the path in adopting digital technologies, but analysis of STCF workshop responses is still outstanding.

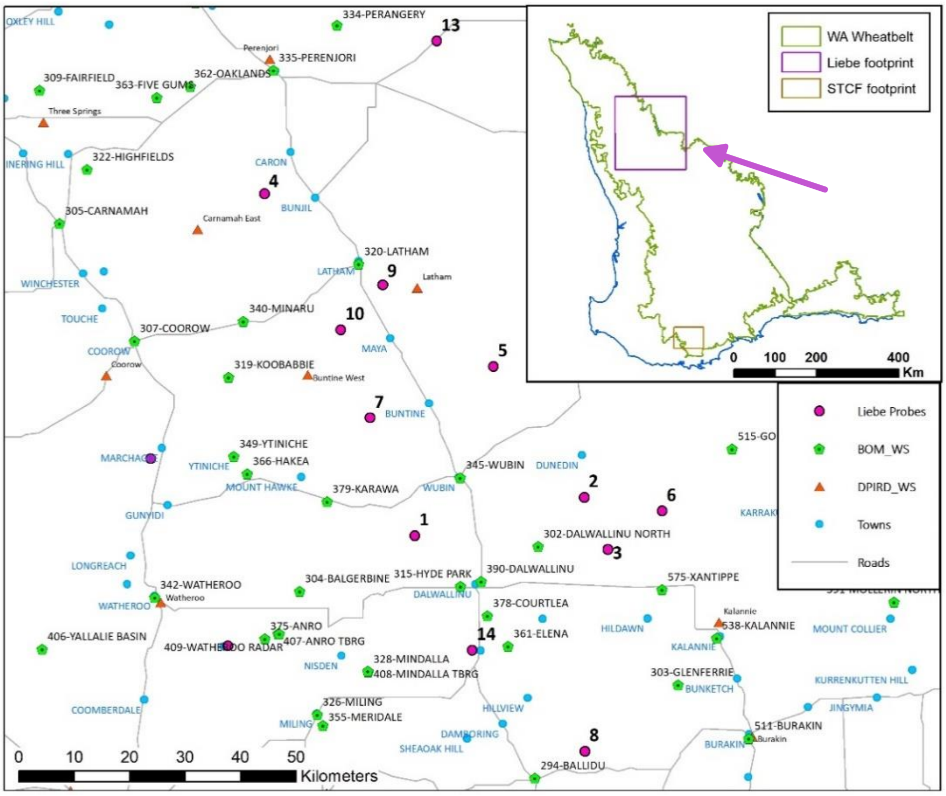


Figure 10 Distribution of installed soil moisture probes within the Liebe Group area footprint. The insert map shows the location of footprints for both groups in relation to the WA Wheatbelt.

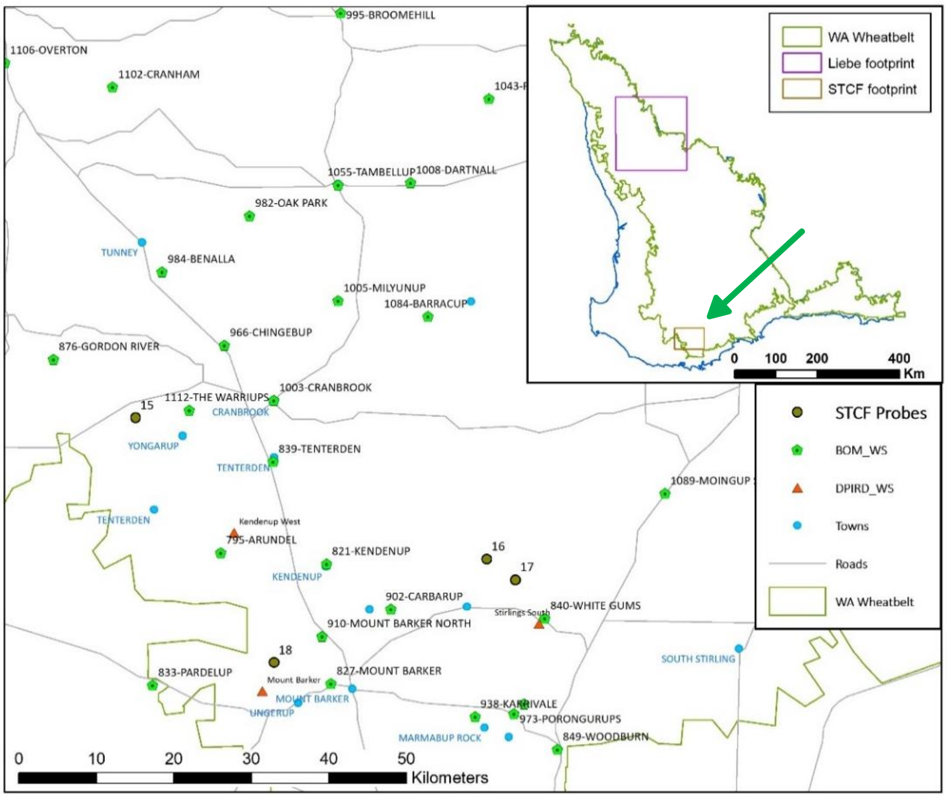


Figure 11 Distribution of installed soil moisture probes within the STCF Group area footprint. The insert map shows the location of footprints for both groups in relation to the WA Wheatbelt.

2.2 Grower Survey's and Workshops

CSIRO, with the Liebe group obtained human ethics approval through the CSIRO Clearance Committee, with approval number 147/22 to conduct a one-on-one grower survey and run workshops with growers from the Liebe Group in Dalwallinu, Western Australia and the Stirlings to Coast Farmers group in Albany, Western Australia. Surveys were conducted as near as practicable to the end of harvest (December / January) 2022. The workshops were run in Albany on Thursday, March 16, 2023, and in Dalwallinu on Wednesday, March 22, 2023. Five growers and an Industry representative attended the workshop in Albany, and 13 growers attended in Dalwallinu.

2.2.1 Survey Responses

Climate and Weather

Growers expressed a strong interest in weather data, as this drives their everyday decision making and seasonal planning activities. Table 2 explores the question of adequacy of network weather stations to providing accurate rainfall records with which to drive simulation models for each of the farms. From the grower's perspective, the automatic weather stations are inadequate for planning purposes. Dalwallinu (008297) is the only automatic weather station in the district for members of the Liebe group, and often this weather station is 40 km or more from the farm. These weather stations are used for crop simulation modelling for the farm. As a result, the lack of close, reliable weather data complicates the use of decision aids by the farmers.

Additional probes and weather stations were installed, as part of the project. The 14 probes installed by Liebe participants, the first ranked network weather stations (by distance to probe) were on average 12.1 km from the probes and ranged from 5.5 to 19.8 km (Table 2). For the STCF probes the average distance from probe to first ranked station was 9.8 km and ranged from 4.0 to 18.0 km. That is, the weather station and probe were in separate locations, and this further complicates the interpretation of information generated by a probe for management.

Table 2 Distance from soil moisture probe to nearest network (BOM or DPIRD) weather station for the Liebe probes (1-14) and the STCF probes (15-18).

	Rank by distance (km)					Rank Locality name			
Pdk_ID	**1**	**2**	**3**	**4**	Mean	**1**	**2**	**3**	**4**
1	12.3	12.6	14.5	17.1	14.1	Wubin	Hyde Park	Dalwallinu	Karawa
2	12.9	22.4	22.4	24.6	20.6	Dalwallinu North	Xantippe	Wubin	Dalwallinu
3	11.80	12.89	22.82	24.32	17.96	Dalwallinu North	Xantippe	Dalwallinu	Courtlea
4	13.3	21.5	22.6	23.4	20.2	Carnamah East	Latham	Perenjori	Oaklands
5	19.8	21.6	30.6	33.6	26.4	Latham	Wubin	Latham	Buntine West
6	13.9	17.3	22.4	22.7	19.1	Xantippe	Goodlands	Kalannie	Dalwallinu North
7	14.0	17.9	19.0	24.5	18.9	Buntine West	Karawa	Wubin	Latham
8	10.6	13.3	19.8	20.1	16.0	Ballidu	East Kondut	Kondut	Glenferrie
9	5.5	6.1	21.7	26.0	14.8	Latham	Latham	Buntine West	Minaru
10	10.5	12.5	15.0	18.5	14.1	Buntine West	Latham	Latham	Minaru

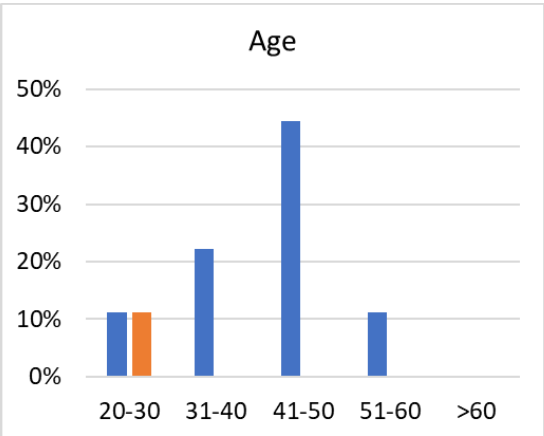
11	14.1	16.6	17.8	20.1	17.1	Ytiniche	Hakea	Coorow	Koobabbie
12	6.3	8.7	8.9	14.6	9.6	Anro	Anro Tbrg	Watheroo Radar	Watheroo
13	18.5	20.4	24.0	30.2	23.3	Perangery	Karara	Wanarra	Perenjori
14	6.4	6.7	11.8	12.6	9.4	Elena	Courtlea	Hyde Park	Dalwallinu
15	18.0	19.6	21.8	25.9	21.3	Cranbrook	Kendenup West	Tunney West	Frankland
16	10.8	13.9	19.3	20.2	16.0	Stirlings South	Carbarup	Porongurup North	Porongurup
17	6.5	16.0	16.5	17.3	14.1	Stirlings South	Porongurup North	Carbarup	Porongurup
18	4.0	7.9	14.5	16.6	10.7	Mount Barker	Mount Barker	Kendenup	Carbarup

Note: Coloured cells are Bureau of Meteorology weather stations, white cells are DPIRD weather stations

2.2.2 Demographics of the Grower Groups

There were 19 responses to the workshop survey, with 15 from the Liebe Group and 4 from STC. An additional entry survey was conducted and 8 were received from the Liebe group and 5 were received from STC. All participants were males, they all manage family enterprises, and no corporate businesses took part in the survey. Mean age was in the 41-50 yr group but ranged from >20 to < 60 years (Fig 3a). All farm businesses have been in operation for more than 20 years, but the length of time that participants had been operating the business ranged from less than 5 years to greater than 20 years (Fig 3b). About 80% of Liebe farms were greater than 6000 ha (Fig 3c), cropped more than 80% of the land (Fig 3d) with an average annual rainfall of 305 mm and an average GSR of 221 mm (Fig 3e).

a)



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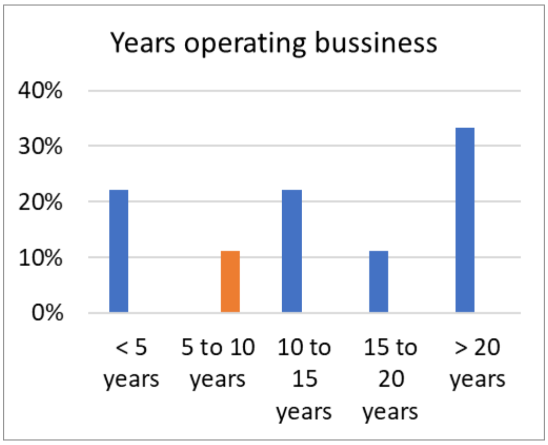

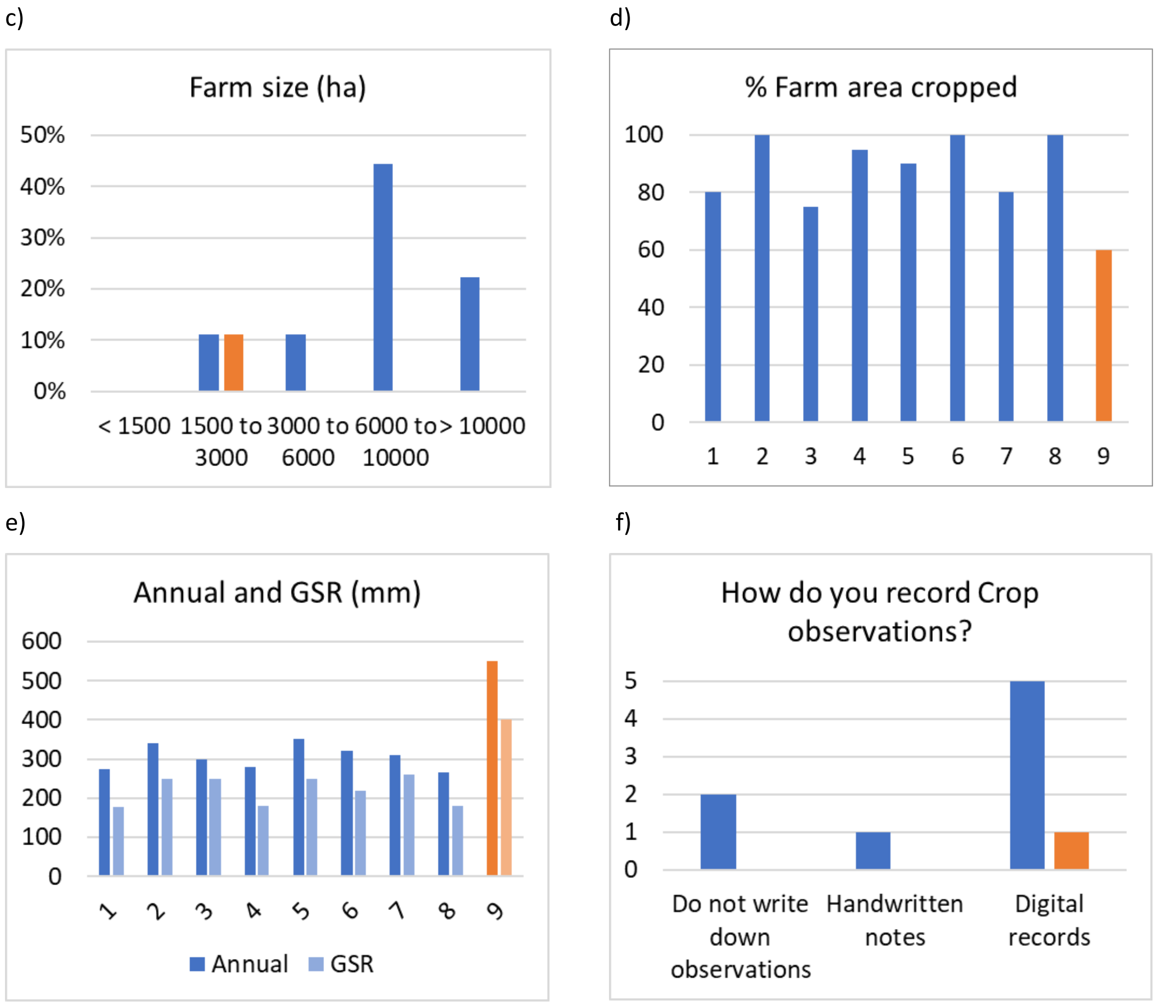

Figure 12 Key demographics for respondents of the initial surveys (Blue bars indicate data from Liebe Group, orange bars show data from STCF)

2.2.3 Analysis of technology use

Table 3 List of digital services and tools commonly used by participants from Liebe and STCF groups and percentage of survey participants using them (WS Q3).

Digital services and tools commonly used by participants	Liebe %	STCF %
Weather Forecasting	100%	75%
Yield Mapping	100%	75%
Satellite Imagery (NDVI)	100%	75%
Weather Stations - On-Farm	100%	50%
Weather Stations - Off-Farm (neighbours, DPIRD, BoM, etc.)	100%	50%
Soil Moisture Probes	100%	50%
Variable Rate Mapping	80%	50%
Soil Mapping (EM and/or Gamma Radiometrics)	30%	0%

Drones	10%	0%
Livestock Management (eID & electronic animal records)	0%	50%
Water monitoring (Flow or tank level)	0%	25%

With 9 out of a potential 14 respondents, on average participants use 7 of the 10 technologies listed.

Table 4 Major sources of CURRENT WEATHER **data identified by participants and percentage of survey participants using them (WS Q4).**

Sources of **CURRENT WEATHER** data	Liebe %	STCF %
BOM	100%	50%
STC Net (FieldClimate, WildEye, Weatherlink)	90%	50%
DPIRD	70%	75%
Weatherzone/Elders Weather	40%	25%
Windy.com	40%	0%
Willy Weather	30%	25%
Others#	20%	0%
#Others identified include Meteologix, OzForecast and Metvuw		

On average, each participant identified 4 options for accessing current weather data. The Bureau of Meteorology (BOM) was listed by all 9 respondents, followed by the STC Net =8 and DPIRD = 7.

Table 5 Major sources of FORECAST WEATHER **data identified by participants and percentage of survey participants using them (WS Q5).**

Sources of **FORECAST WEATHER** data	Liebe %	STCF %
BOM	80%	50%
Weatherzone/Elders Weather	30%	50%
DPIRD	30%	25%
Windy.com	30%	0%
Willy Weather	20%	50%
STC Net (FieldClimate, WildEye, Weatherlink)	20%	0%
Others#	40%	25%
#Others identified include Meteologix, Agromet, MetEye, OzForecast and Metvuw		

The number of sources used for forecast weather data were lower, with an average of 2.44 options across the 9 respondents. With an additional 5 other data sources identified beyond the 6 listed by the survey. BOM was the most frequently used source by 7 of the 9 respondents, all other options receiving 2 or 3 counts.

In relation to ranking the reliability of the forecasting weather data (WS Q6), the assessment was well balanced with 5 respondents on “Fairly reliable” (75%) and 4 respondents with “Somewhat reliable” (50%). A lack of votes for the "Very reliable (100%)“ confirms the sentiment expressed by many during the workshop, that they still want/need greater accuracy or reliability in weather forecasting, in particular, longer-term forecasts. On the other hand, a lack of votes for the Poor (0%) and Moderate (25%) categories suggests participants may have found such sources of data but could have quickly dismissed them for better alternatives.

Table 6 What farm management/technology apps are you currently using?(Q7)

Technologies currently in use	Liebe %	STCF %
My John Deere (Operations Centre)	80%	75%
AgriMaster	70%	50%
CSBP Decipher or Summit Fertilizer App	60%	75%
AgWorld	60%	25%
SMS Basic or Advanced	50%	50%
Other (please specify)#	50%	0%
AFS Connect/PLM (Case or New Holland)	40%	0%
PCT AgCloud	20%	25%
Xero	20%	0%
BackPaddock	10%	25%
AgriWebb	0%	25%
Agata / Phoenix	0%	0%
Mobble	0%	0%
Maia Grazing	0%	0%
# Others identified include CBH Load Net, Safe_Ag_Systems, Agritrack, Excel, Production Wise		

Table 7 Key challenges identified with technology adoption/use and percentage of survey participants reporting them(Q11).

Key challenges identified	Liebe %	STCF %
Interoperability - dealing with different platforms (machinery, software providers)	90%	75%
Time - just not enough hours in the day to do it	80%	50%
Machine setup & compatibility - getting my data in or out of machines	60%	50%
Value - is it financially worth doing it?	50%	25%
Experience - just not sure what is out there?	10%	50%
Support - not sure where to start or how things work?	10%	0%
Knowledge - I'm just not tech savvy enough	0%	25%
Other#	0%	25%
#Others identified by STCF participants relate to practices of livestock industries (stock and pasture)		

Participants were asked what the biggest challenges with technology use and adoption that they experienced (Q10, Table 7). The most common issues were:

- Interoperability was listed by 90% of Liebe and 75% of STCF
- Time (not enough hours in the day) was listed by 80% of Liebe and 50% of STCF
- Machine setup & compatibility - getting my data in or out of machines was listed by 60% of Liebe and 50 % STCF
- Value - is it financially worth doing it? Listed by 50% and 25% respectively.

However, 60% of Liebe participants felt they had a good level of comfort in applying new technology while 20% each were either “Excellent” or “Neither poor, nor excellent”(Q12).

The technologies participants were most interested in learning or integrating next were(Q13):

- Green-on-Green (4)
- VRT (2)
- Yield Maps, Integrating Deep Soil testing, N-Modelling, APSIM*, CSIRO Models* and Accurate modelling were listed once each (*indicates Industry rep in STCF workshop)

The technologies participants wanted most help with from either the Grower Group, or from a consultant were (Q14):

- Plant Nutrient Sensors - Liebe
- GIS data aggregation - Liebe
- N-Modelling - Liebe
- Plant available water in relation to various soil types and locations - STCF
- A dashboard to take all data in, analyse it the way wanted and presented clearly - STCF

In relation to the main barriers to improving current monitoring practices through technologies? The average rankings within each group were:

Table 8 Main barriers to improving current monitoring practices through technologies and the mean ranking by survey participants reporting them (the higher the ranking, the greater the need for support in adoption (Q15)).

Main barriers to improving current monitoring practices	Liebe %	STCF %
Time and effort- the ability to implement	6.30	4.75
Access to consultants who can help me	4.89	4.33
Cost of infrastructure - up- front pricing & ongoing software subscriptions	4.50	5.00
Uncertainty of$ return from investment	4.50	3.33
Cost of infrastructure - my equipment is not currently capable/compatible	3.20	4.00
Knowledge - Not sure about all the available tools	3.10	5.50
Data - Limited existing data to utilize in decision making	2.89	2.67
Additional skills required to implement	2.40	4.67
Not interested/ don't like it	2.25	1.00

There was strong agreement in the rankings between the two groups in all but two barriers, Knowledge of available tools and Additional skills required to implement them, which were given a higher ranking by STCF, and this may in part be explained by a greater focus on livestock monitoring practices.

Comparisons between groups in solving impediments to adoption and implementation suggest that efforts to develop aids would be well justified by both groups. The comparisons also suggest the potential for identifying “technology champions” within each group that could do both internal and cross group extension/training with a strong perspective of what producers actually want. But champions would probably require a reasonable level of support for delivering this information.

Table 9 Combined analysis of Tables 3, 4, 5 and 6 (above), classified into key activity classes and sorted by % of Liebe and STCF respondents using them.

Activity	Tech	Liebe%	STCF%
Weather	Weather Forecasting	100%	75%
Weather	Weather Stations - On-Farm	100%	50%
Weather	Weather Stations - Off-Farm (neighbours, DPIRD, BoM, etc.)	100%	50%
Farm Monitoring	Yield Mapping	100%	75%
Farm Monitoring	Satellite Imagery (NDVI)	100%	75%
Farm Monitoring	Soil Moisture Probes	100%	50%
Current weather	BOM	100%	50%
Current weather	STC Net (FieldClimate, WildEye, Weatherlink)	90%	50%
Farm Monitoring	Variable Rate Mapping	80%	50%
Forecast Weather	BOM	80%	50%
Current weather	DPIRD	70%	75%
Farm management	My John Deere (Operations Centre)	70%	75%
Farm management	CSBP Decipher or Summit Fertilizer App	60%	50%
Farm management	AgriMaster	60%	50%
Farm management	SMS Basic or Advanced	50%	25%
Farm management	AgWorld	50%	25%
Farm management	Other (please specify)	50%	0%
Farm Monitoring	Soil Mapping (EM and/or Gamma Radiometrics)	30%	0%
Farm Monitoring	Drones	10%	0%
Farm Monitoring	Livestock Management (eID & electronic animal records)	0%	50%
Farm Monitoring	Water monitoring (Flow or tank level)	0%	25%
Current weather	Weatherzone/Elders Weather	40%	25%
Current weather	Windy.com	40%	0%
Current weather	Willy Weather	30%	25%
Current weather	Others	20%	0%
Forecast Weather	Others	40%	25%
Forecast Weather	Weatherzone/Elders Weather	30%	50%
Forecast Weather	DPIRD	30%	25%
Forecast Weather	Windy.com	30%	0%
Forecast Weather	Willy Weather	20%	50%
Forecast Weather	STC Net(FieldClimate, WildEye, Weatherlink)	20%	0%
Farm management	AFS Connect/PLM (Case or New Holland)	40%	0%
Farm management	PCT AgCloud	20%	0%
Farm management	Xero	20%	0%
Farm management	BackPaddock	10%	25%
Farm management	Agata / Phoenix	0%	0%
Farm management	AgriWebb	0%	0%
Farm management	Mobble	0%	0%
Farm management	Maia Grazing	0%	0%

Farmers used technology for weather, farm monitoring and farm management decisions. The highlights from the technology analysis were:

2.2.4 Weather

- 100% of Liebe use on-farm, off-farm and forecasting weather data sources
- 100% use BOM, 90% use STC Net and 70% use DPIRD for CURRENT weather. Other options only account for 20-40% of respondents
- 80% of Liebe and 50% of STCF used BOM for **Forecasting** weather. Other **Forecast** tools accounted for 20-40% of respondents.
  - Meteologix, Agromet, MetEye (BOM), OzForecast, Metvuw, Meteoblue were other forecasting tools identified by participants.

2.2.5 Farm Monitoring

- Of the Farm Monitoring tools, soil moisture probes, yield mapping and NDVI were used by 100% of Liebe and 50-75% of STCF. VRT was used by 80 and 50% respectively. All other tools were less than 30%, but for Livestock management STCF had 50% uptake with Liebe at 0%.
- Soil Mapping (EM & Gamma) had surprisingly low uptake (30%).

2.2.6 Farm Management

- No one single Farm Management tool had 100% uptake
  - MyJohnDeere, CSBP Decipher and AgriMaster were used by 60-70% of Liebe and 50-75% of STCF
- SMS Basic and AgWorld were used by 50% of Liebe, but only 25% of STCF
  - CBH Load Net, Safe Ag Systems, Agritrack, Excel and Production Wise were other Farm Management tools identified by participants
- My John Deere (MJD) and AgWorld were listed by 50% of Liebe as the top two Apps used on-farm in Question 8. 10 other tools were listed, but only once each indicating large variety of options available to farmers

Q 17 What technology solutions do growers need assistance with?

Growers are most interested in integrating satellite imagery into decision making. The technology does provide growers with a solution to the problem, and they requested insight to "explain what the numbers mean". They were interested in integrated digital solutions, that enabled them to visualise all of their digital data (table 10).

Table 10 Ranking of identified areas of interest where Grower Groups could provide the most help with training and implementing. (The higher the ranking, the greater the need for support in adoption (Q17))

Technology	Liebe	STCF
Integrate satellite imagery into decision making	4.70	4.00
Explain what the numbers mean	4.67	4.67
Weather station options & AgTech solutions on-farm	4.30	4.33
Getting farm production data into one spot (i.e yield maps into 1 platform)	3.90	4.00
Improve farm connectivity	2.88	3.50

How to design on-farm machine-width field trials	2.78	2.50
How to clean/edit yield data	2.50	4.25
How to make variable rate maps	2.11	2.75
Livestock data management - eID, pedigree or production data management	1.33	5.25

Nine key technologies were identified that if adopted could provide significant benefits to the process of within season decision making in a timely manner. They were ranked based on the producer's need for grower group support in training. Again, there was strong agreement in the rankings between the two groups in all but two technologies (Table 10), with the exception of "How to clean/edit yield data and Livestock data management", and for both of them it is likely that a) Liebe participants are further advances in understanding the processing of yield data, while b) they have little need for improving skills in livestock data management.

The preferred format in which the grower group support should be delivered was explored and reported below. The willingness to participate in training workshops and to receive additional training through YouTube tutorials as the primary methods of delivery indicates a well-developed understanding of delivery through digital media, which is likely to facilitate adoption once the right information is made available.

Table 11 Preferred method of delivery of support by the grower groups (Q18).

Preferred method of delivery	**Liebe**	**STCF**
Training Workshops	70%	75%
YouTube tutorials	70%	50%
On-site Support	50%	25%
Manufacturer led training (i.e John Deere rep's holding a workshop)	30%	25%
Train Manuals	20%	
Podcasts	10%	
Visible outputs of Trial data - Virtual Field days		25%

However, it is important to keep in mind some of the feedback from Q 16 "The thing that annoys me most about technologies are" to minimise the issues highlighted by the results from Q11 (see Table 7 above)

- Tools and information become outdated soon after purchase
- Technology sufficiently developed to require minimal upkeep/upgrade
- Tools should be Plug and Play
    - Tools and solution match up and deliver as expected
    - Should not require extensive wiring to connect
- The benefit of ROI vs time/$ to implement should be clearly understood
- And most importantly, wherever possible should avoid the use "manually filled surveys"

2.3 Workshop Results

The interactive workshops, that displayed each of the key technologies including crop models, satellite imagery, yield maps, soil moisture sensors and weather stations were all discussed. As technology was mentioned, growers then commented on that technology. Key findings related to each technology component are discussed.

2.3.1 High Resolution imagery from UAVs or satellites

Growers were concerned about the value proposition of these data. There is a need to link the information to an action. For example, what information does NDVI provide? It could relate to crop yield, and it could relate to weeds? The data provided cannot easily be incorporated into existing platforms that growers use, and this complicates visualisation, interpretation, and action. Slow internet speeds, and data processing storage and cost were also an issue. There is a need to link the transition from being able to detect something with a sensor (weeds) to a timely change to management in response to the new information and then business analytics ($) flowing from that. Commercial UAV services, and UAVs available to farmers are unable to survey large areas. The data processing process to recognise attributes like weeds or disease is not viable, and data cannot be turned into an action.

2.3.2 Soil Water Information

Growers were interested in interpreting soil water information and relating it to a critical management decision. To do this, they needed to better conceptualise what the graph meant in both space and time, to then link this information to a management decision. In terms of time, growers wanted to understand if the soil water data were wetter or drier than the previous season or two. About space, growers wanted to know how representative the soil moisture sensor was of the entire field. They were also interested to know if their soil water sensor provided them with insights for other fields. STCF have 10-12 soil water probes – no point in time reference to interpret the graph. Growers were also interested in combining information from soil moisture probes with weather forecasts.

Other issues and questions that growers highlighted with soil moisture probes included:

- Trafficability with farm machinery
- Visualisation and interpretation of soil water data
- Time to settle after install of soil moisture probes
- Understanding depth effects and interaction with soil constraints such as compaction
- Leeching effects were useful, but needed the ground truthing
- Consistency across a paddock or farm vs points of probes (or analysis)
- Variability due to a good finish or timing of rain – so many factors for water
- Rooting depth in plant available water images (agronomic interpretation)
- How to calculate mm of plant available water?
- Can you relate PAW to critical agronomic decisions at various times of the year?

2.3.3 Crop Models, including APSIM and Yield Prophet™

Crop models and Yield Prophet are not strategically used by growers. While the technology can help benchmark production, help identify if fields are reaching yield potential and help with N management decisions, few growers warm to these analyses and interpretations. Ideally the technology needs to be combined with grower data, such as a yield map, to maximise its utility. Considerable investment in training, data use and interpretation of crop models would be required for growers to maximise the benefits from them. They also wanted to know if the crop model was representative of their farm. The implication here, is that if it was linked to local soil moisture probes, and local weather stations, growers might consider the information more valuable. Multiple growers have requested a direct linkage between crop models and sensors, where the data was displayed in an easy to interpret platform. Growers expressed the need to trust the model output to use it for decision making, and wanted output from different technology offerings, such as soil moisture probes and crop models to be displayed seamlessly together. The Stirlings to Coast group have soils that are prone to waterlogging. APSIM cannot cope with this constraint. The growers commented that they would be more likely to use outputs from the model if they knew it could cope with waterlogging.

2.3.4 Yield Maps and Remotely Sensed imagery

There was a mixed response from participants during the workshops on using yield maps, although the post-workshop survey showed 100% use by respondents. The value from analysing yield maps was perceived to increase if producers could analyse more than one year at a time as well as several paddocks at a time if all had the same crop type. For example, yield maps were used to identify regions on the farm to target for amelioration.

Processing of all maps within a year to standardise values and mosaicking to analyse at the whole farm scale was in the wish-list of several producers, but not something that could be achieved easily with the current software processing offerings, linked to specific brands of machinery.

However, despite the industry platforms, growers still found that processing, using and interpreting yield maps was troublesome. Furthermore, a yield map does not provide an explanation for a constraint. It could be frost, waterlogging, nutrients, disease or weeds that contribute to a low yielding region. The mapping software and commercial platforms are not intuitive. Some packages do not allow you to visualise the whole farm, and the packages can struggle to accommodate two headers. However, these data were valued by farmers.

Earth observation imagery, transformed into an NDVI (normalised difference vegetation index, (Near Infra-Red - Red) / (Near Infra-Red + Red)), were viewed by many growers, on commercial platforms. It was considered interesting, but like yield maps, the basis for high and low regions was difficult to discern. There was some interest in overlaying insights from multiple years. The imagery could help identify regions where drainage management was required.

2.3.5 Delta T

Weather data, modified to provide growers with insight into spraying conditions was highly valued. It was discussed at length by growers, and arguably the most useful from the grower's perspective in term of helping them manage their day to day spraying operations. Unlike some of the other technologies, Delta T provides a direct link between information and a management action. Despite this, there was some concern that the information provided by SprayWise (https://www.spraywisedecisions.com.au/) was not accurate in the STCF. There was a general agreement that forecastable spraying conditions were vital, and growers would like more information about spraying at the extremes of delta T to understand the cost penalty associated with spraying in sub-optimal conditions. This would need to be allayed with high resolution data on weed populations across the paddock, which do not currently exist.

2.3.6 Other tools and technologies

Growers were interested in understanding where to invest time and resources, and decision aids that assisted with this process would be considered useful. The precise nature of these decision aids was difficult to define, although costs and returns were frequently mentioned.

Growers universally wanted better weather forecasts, both in the short term, and for the growing season.

Again, growers universally wanted to understand, map and manage both biotic and abiotic stresses. This suggests that existing tools do not properly map these problems (pathogens, weeds, pests, frost, heat, waterlogging) with sufficient spatial and temporal accuracy to make an informed management decision. The technology in its present form, is not good enough to help growers decide what management action to take. The technology needs to improve to be useful and must target a specific problem.

3 Conclusion

Agricultural technology is pervasive, and results from this project demonstrate that farmers are willing adopters of new technology. Each grower was using at least 7 technology pieces, which could include yield maps, soil moisture sensors and weather monitoring sensors. Other technology, such as earth observation imagery and insights provided by crop models were also considered but were not as widely used. Importantly, the technology that was adopted served a clear purpose and provided intelligence to the farmer that was valued and influenced a management decision. Across all technologies, growers wanted the technology to be supported, either through a consultant or through a service offering provided by the company.

The findings in this report are in agreement with earlier surveys of farmer adoption of technology and align with the concepts associated with technology acceptance models. That is, the adoption of the technology highlights the importance of perceived useability and perceived ease of use (Pierpaoli et al. 2013). The most highly valued, and used technology was Delta T. The tool interprets weather information and assists with the decision to spray herbicide. The purpose of the tool is clear, and it is relatively easy to use. This technology contrasts with almost all other technologies, as the link between the information, the decision and the action arising from the use of the technology are less certain.

For example, a soil moisture sensor can assist with the decision to sow a crop, the decision to plant a certain area to a particular crop type, or the decision to apply nitrogen. All of these decisions require local context and considerable nuance. Despite this, the technology was considered valuable, but farmers wanted it integrated into other technologies such as crop models and yield maps to provide them with more spatial and temporal context. Therefore, the information and action arising from the information is less clear that that provided by Delta T.

To that end, growers' requests are remarkably straightforward and clear. That is, they would like to know when and where the biotic and abiotic stresses are likely to occur on their farm, and how they should manage these constraints given prevailing weather and climate forecasts. They would like to know the decisions they should make given these abiotic and biotic stresses. The information should be presented in a readily digestible manner, preferably on a single platform or dashboard.

Growers are managing a farm business, so intelligence about commodity markets, that aligns with product information on their farm was also considered useful.

The ability to define the grower's needs with such clarity following expositions of technology, workshops and surveys is unique. It suggests that technology has improved in the last decade, and it is now possible to conduct such a survey. It is also clear that much of the technology shows promise, but is at the early stages of evolution and adoption. Agricultural technology companies and researchers must work more closely with growers to develop the technology into a useful product. These useful products must provide intelligence on farm attributes that growers value, and deliver the outputs in a form that farmers can readily consume. The technology must be supported by a service network, to ensure the technology services the real needs of the industry. The implication is that if technology was genuinely useful, farmers would be prepared to pay for a service. This last insight contradicts some studies about farmers' willingness to pay, but it could be that the technology delivered to date has not been able to fulfil farmers' needs, and this influences their desire to pay for technology.

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