Innovating down the cost curve by trial and adoption of successive innovations on a large scale, specialist grain enterprise

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1 Abstract

A study by Kingwell et al (2014) identified that while scale economies underpin Total Factor Productivity (TFP) growth, farm performance was also critically important. Farm performance was driven only by 'the farm manager's preparedness and ability to use cropping innovations and their skill in organisation and time management'. This paper uses the Jones' property in Tammin to provide a case study of how a farm can achieve improved TFP through adoption of cropping innovations, organisation and time management. The Jones' dominant business philosophy for their 10,000 ha grain enterprise is to achieve target returns with secure cashflow. To secure cashflow, they seek to avoid negative event outcomes that have unknown probabilities. Secure cashflow implies that they can use comparatively small amounts of that cashflow to de-risk innovations designed to lift returns by lowering costs and securing market opportunities. The outcomes from selected innovations are trialled, measured and assessed and are subsequently adopted across the farm if target returns are met. Their approach is the detailed subject of this paper, with specific exploration of the efficiencies they plan through logistical efficiencies via the adoption of WiMesh intra farm connectivity coupled with sensors across the farm (trial, 20% of farm: 2018 / full adoption: 2019) in boom operation. Similarly, their connectivity is also employed to deliver a range of other benefits, particularly related to weather event decision making. Cumulatively, these changes are designed *to* drive all in per hectare costs to comparatively low levels and increased TFP across the farm. The Jones' report that IT integration has resulted in a definite improvement to the farm's modus operandi, as it compliments other means to reduce management complexity. The Jones' won the '2016 Cropper of the Year award maximising technology and science, (that works) on an impressive 15 per cent return on investment – more than three times that achieved by the average WA grain farm' (Wagstaff, 2017). Importantly, the Jones' have sufficient management depth and financial resources to devote to the adoption of on-farm agtech; indeed, it is integral to their business success.

However, ongoing competitive pressure from emerging competitors imply that further efficiency gains at farm level and along supply chains, in addition to innovations to deliver a greater array of value to customers (i.e. value chain formation), will be needed for the industry to remain competitive. From a public policy perspective, at issue is the best means to affect the greatest industry wide gains through adoption of an objective of TFP growth. Opportunities to create and encourage the adoption of low cost options for smaller, more capital constrained farms to access the benefits of digital agriculture, defined as 'having the right farm data at the right time to make a better decision' will be essential to reduce costs. To this may be added securing the human capacity to use this data on farm, and in keeping with Kingwell et al (2014) above, the role of targeted public extension to drive adoption and TPP growth by skills that lessen management complexity. On farm trialling to establish the validity of claims made about new technologies may also play an important role in accelerating the adoption of these technologies (Jackson and Malcolm, 2018)

This is the first of a six paper series on farmer agtech adoption in the WA grains industry that use open source information technology devices to solve for production problems that

[1] Department of Primary Industries and Regional Development

increase productivity. The first five papers are case studies[2] outlining the business drivers of the adoption of differing types of AgTech adoption. A key proposition under investigation is that the particular circumstances of a farm implies that each farm will have a different path of open source information technology adoption that will give it the best risk adjusted rate of return. They consider the variables of farm scale (three are at or above minimum efficient scale[3] – MES - for cropping), enterprise mix (three are mixed farm operations), rainfall zone and management structure / depth and group vs. single farmer adoption. The sixth paper is a summary document of key themes, - including the interaction of adoption with on and off farm connectivity and data integration - and public policy implications. It will discuss private and public structural and strategic options to deal with connectivity and complexity issues that are necessary for WA agriculture to access the productivity gains possible from adopting the full suite of available technologies.

Interested readers are directed to a video link[4] of a 'farm table discussion' on Bungulla's system between Mr. Jones and the author.

2 Paper rationale: Driving efficiency gains and public policy

2.1 Profit consists of Terms of Trade and Total Factor Productivity

A farmer's profit function can be broken into terms of trade (ToT) the ratio of output prices to input prices and total factor productivity (TFP), the ratio of outputs to inputs. TFP is not tonnes of grain per hectare (T/ha), which means that profits can rise even if output falls as long as inputs fall proportionally more. Farmers are largely price takers, so increasing TFP is a key means of increasing and sustaining profit.

2.2 Total Factor Productivity growth…

Using data supplied by agricultural consulting firms, Department of Primary Industries and Regional Development (DPIRD) economists Kingwell et al (2014) employed O'Donnell's (2011) methods to measure TFP across 270 farms in the WA broadacre sector between 2002 -11. Socio-managerial and training data on the farm families also complemented the physical and financial datasets used. The research indicated that crop dominant farms had treble the TFP growth of sheep dominated farms and that 'growing farms' (those with increased equity and profit in at least seven of the ten years) had twice the TFP growth of 'less secure farms' (those with reduced equity and no profit[5] each year).

2.3 … Driven by scale, cropping innovations and training to improve decisions

A key insight of this study was that while scale economies underpinned TFP growth, farm performance was also critically important. Farm performance was driven only by 'the farm manager's preparedness and ability to use cropping innovations and their skill in organisation and time management'.

Among the more important cropping innovations observed were use of minimum tillage techniques, air seeders, press wheels, use of pasture phases to reduce weed burdens and

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[2] Cases one and two are complete and available.
[3] Minimum efficient scale in WA grain production is 'one tractor size' or 'unitisation scale'; that is a minimum of around 4,000 ha and a maximum of around 6,000 ha before needing additional machinery.
[4] https://www.agric.wa.gov.au/crops/econnected-resources-and-links
[5] Allowing for finance cost, depreciation and unpaid family labour

strategic seeding to lessen weed problems. Many of these innovations are embodied in technology that comes with new machinery.

Organisational and time management (OTM) skills were driven by increases in human capacity, which were driven by the level of training received by farming families. 'Note, that the training is not the level of formal education but rather the extent of enterprise training provided by the private and government sectors that the members of the farm family have participated in' (Kingwell, et al, 2014). Efficiencies in OTM are significant as modern farming is complex and farms are increasingly 'large, multi-enterprise businesses underpinned by extensive capital investments, changing production technologies, volatile markets and social and climate challenges' (Kingwell, 2014). These skills are also required for farmer integration into developing value chains.

2.4 Barriers to IT adoption

Information technology (IT) adoption can be a low enough cost option to be affordable to many more farmers than currently use the technology. Adoption can be transitioned across a farm when new equipment is purchased. However, many farmers, particularly smaller ones, have limited contemporary exposure to IT in a farming context which is potentially compounded by the increasing average age of farmers. Furthermore, limited internet connectivity, unfamiliarity with IT and a lack of related skills has effectively slowed the rate of adoption among a sub set of other farmers who have invested in soil mapping. This implies, that without public intervention to improve connectivity, IT familiarity and related skills to reduce management complexity, the rate of adoption will depend upon the rate of farm consolidation (to the extent that consolidators are technology savvy and have internet or across farm connectivity and develop management systems to reduce complexity), which may or may not be optimal from a societal perspective particularly if regional areas become denuded of population. Furthermore, the rate of adoption will also be determined by industry's ability to attract technology savvy personnel from other sectors and train them in agricultural specific skills. Training farmers to at least to a level where they are able to effectively interact with specialist providers implies less information asymmetry between them and more efficient contracting; well informed consumers are more likely to make better purchase decisions. At issue is whether public funding to speed up the rate of technological innovation and adoption is a worthwhile expenditure.

2.5 Extension justified if returns to society are greater than the cost

DPIRD (2012) has previously argued that public expenditure on Research, Development and & Extension (R, D &E) activity is justified if it results in a sufficient return to society to pay for the expenditure because of an accelerated rate of productivity growth. That is, the public receives a positive return on its expenditure via increased income. Furthermore, the WA government has signalled that it wishes to foster a more diversified economy able to generate employment, income and an augmented tax base.

Kingwell (2010) also implies that targeted information and extension to develop farmer familiarity with IT has the greatest potential for large productivity gains relative to cost. Pannell (2009) argued that as a tool, publically funded extension will work if sufficient private benefits accrue to the targeted audience so that it is 'adoptable once the extension program ceases.'

2.6 Low cost IT adoption could be a gateway to increased adoption of Precision Agriculture

This paper seeks to demonstrate that sufficient gains from the adoption of low cost technology could be attractive to foster adoption by less technology savvy and capitally constrained farmers. Specifically, low cost actual data from tracking each machine lowers the transaction costs of breaking out actual costs. For instance, the opportunity cost of highly skilled labour engaged in time critical operations recording vehicle movements is less than the value of data. However, the availability of low cost actual data, generated by sensors and collected by computers, which is easily broken out, allows for identification of further small gains that go straight to net profit and to test whether current cost assumptions are robust. Importantly, this type of introduction may lower the barriers to a range of other productivity gains that may not be currently available to these farmers. That is, it may engender scope for further innovating down the cost curve using an enriched data set to aid decision making.

3 Bungulla Farm

3.1 Seasonality creates business uncertainty

The Jones' 10,000ha cropping operation (11,000ha farm) is located at Bungulla, a locality sided with the WA wheatbelt town of Tammin, which is approximately 180km west-northwest of Perth. It is located on the boundary of the medium (M3) and low (L3) rainfall zones (figure 1).

Figure 1: WA Agricultural Zones and Tammin location.

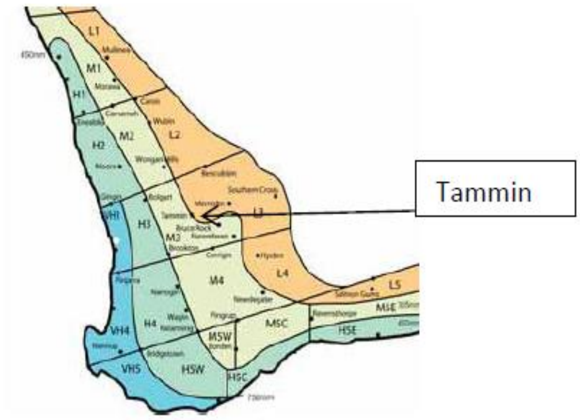
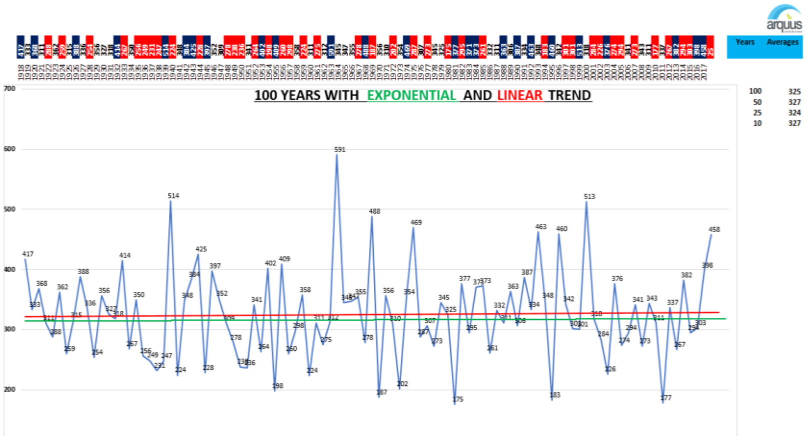


Figure 2 presents Bungulla farm's annual rainfall data for the past 100 years. Note the variation in annual rainfall. A major difficulty associated with this variability is that the optimal inputs for a high rainfall year is different to that of a low rainfall year. High levels of nitrogen (N), suitable to aid plant growth when soil moisture levels are high, can cause N stress on crops, such as quality downgrades and pinched grain. Low levels of N application, suitable in a low rainfall year, implies a loss of yield if soil moisture levels are high. Furthermore, high N levels can be problematic if plants suffer moisture stress during flowering due to hot weather (Table 1) or because of frosts. Figure 3A indicates that Bungulla may experience an overall loss of rainfall in coming years if recent decadal trends persist.

Figure 2: Bungulla Farm – 100 years Annual Rainfall, 1917 -2017



Furthermore, figure 3B indicates that annual growing season rainfall (gsr) averages are also changing with greater incidences of increased summer rainfall. That is, while average annual rainfall has remained consistent, extended autumn droughts and summer rain (i.e. non growing season rainfall) have increased in frequency over the past two decades.

Figure 3A: Annual Rainfall Zones 2000-14 compared with historical data

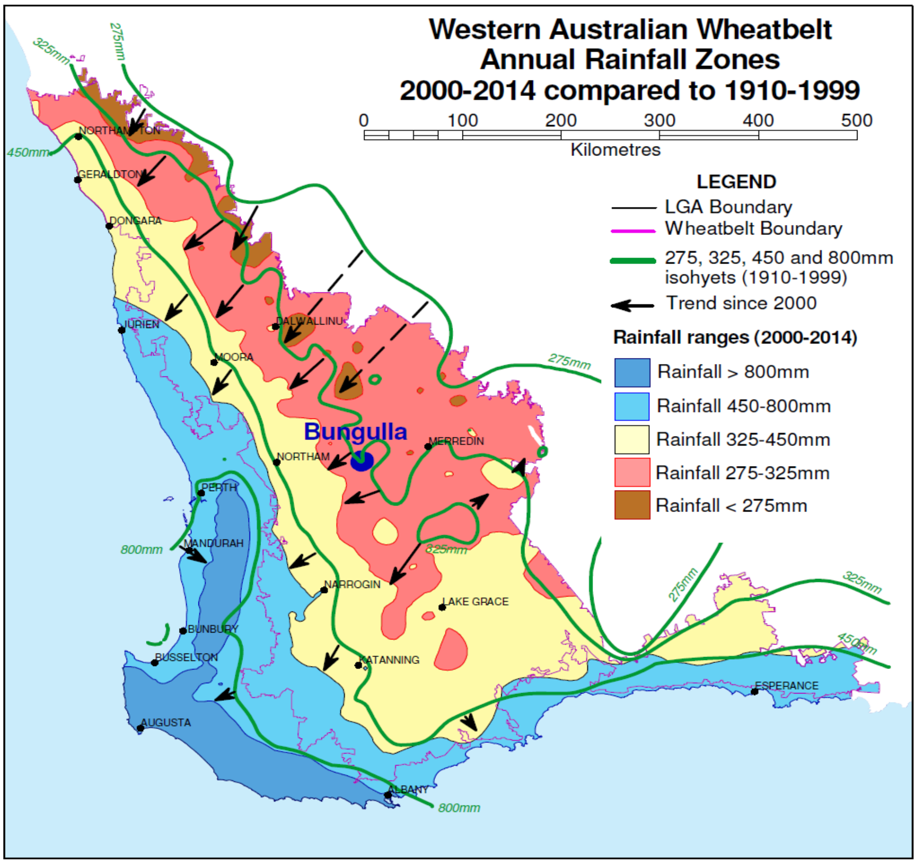


Figure 3B: Growing season rainfall 2000-14 compared with historical data

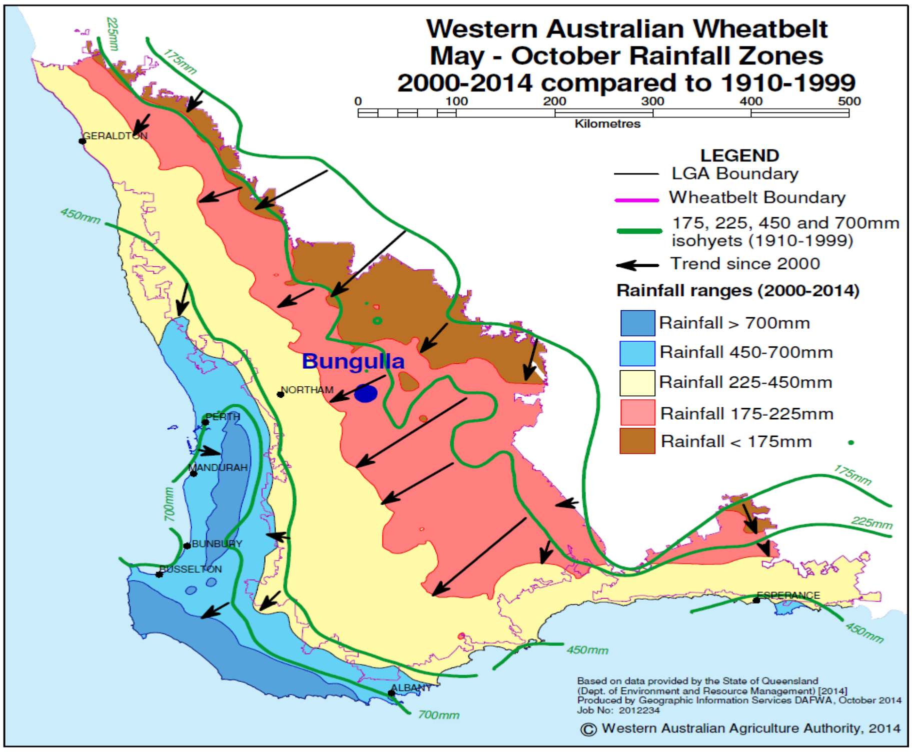


Table 1, data from nearest weather station recording temperature (Kellerberrin), indicates increased instances of hot days during spring crop flowering and anecdotally, Brad reports increased occurrences of frost on the farm.

Table 1: Sept 1 – Oct 7, 1951 - 2017 Temperature Maximums Degrees Celsius, at Kellerberrin (number of days)

	1951-60	1961-70	1971-80	1981-90	1991-00	2001-10	2008-17	2009-14
>30C	11	14	7	11	5	10	19	12
>32C	2	5	2	3	3	5	10	5
>34C	1	1	1	0	0	2	6	4

Source: BOM

The importance of farming within seasonal parameters is that probabilities of these occurrences may be judged, for practical / business planning purposes, to have very low levels of predictability and their consequences for cashflow are potentially severe. These types of events, pertinent to the farmers, whose probability of occurrence cannot be estimated because, ‘by definition such events are infrequent, while also appearing at highly varying intervals’ (Makridakis and Taleb, 2009) can also include market prices, resale machinery prices and currency movements. The farm employs different strategies to mitigate the impact of these occurrences and create stable cashflow – at target rates of returns and greater – which reduces the management complexity of the enterprise.

3.2 *Early rapid growth in scale (capital widening) refocussed to more technology improvement (capital deepening) …*

Formerly a mixed farm, the operation has been grains only since Brad and Kate assumed management since 2006. They also expanded its original 3,600 ha to a contiguous 10,800ha as of 2014. Planfarm/Bankwest benchmark 2016/17 data indicates that the average size farm for M3 and L3 sample wheat belt farms is around 3,800ha and 5,700 ha respectively. Scale efficient use of the farm's machinery kit occurs at multiples of around 4,000 - 6,000ha. Although the farm's machinery kit could accommodate production from another 1,000 - 2,000ha, the farm has not expanded in area since 2012. Rather than capital widening (more land and scale), investment has accelerated its capital deepening through improved technology to better utilise its existing productive base.

3.3 *... including supply chain diversification…*

The enterprise has four business segments: grain production, storage and handling, transport and crop spraying. The middle two reflect the Jones' diversification into new marketing opportunities that better suit their changing pattern of grain production (of lower protein wheat) and their proximity to major livestock feed markets.

The farm makes use of extensive data sets for precision agriculture, much of which is enabled by introduced technology (e.g. global positioning systems, (GPS)) generated by embodied technology in machinery (e.g. yield data from harvesters, auto steer, GPS flow control, Weedseeker) as well as self-generated data (e.g. soil testing, soil test mapping, soil data mapping and predictive yield models).

The Jones' 2016 Australian Cropping Farmer of the Year award resulted from 'maximising technology and science, (that works) on an impressive 15 per cent return on investment – more than three times that achieved by the average WA grain farm' (Wagstaff, 2017). The business' focus on return on investment implies that the commonly thought of measure of productivity – tonnes per ha – is not a focus within itself. Rather a key focus is TFP as commodity producers have limited control over their terms of trade. The farm's capital deepening investment into storage and handling and transport have assisted it to secure improved supply chain TFP, as it is able to fulfil customer requirements regarding quality and timeliness of delivery and win market share to divert grain to a lower cost supply chain.

The business has developed a systematic multiyear approach to data driven decision making. It secured cashflow and invested capital into a structured program to test and apply innovation. Safeguarding cashflow is a business strategy well summed by Warren Buffet's attributed maxim that 'in order to succeed, you must first survive' (in Taleb, 2018).

4 Increasing operational and logistical efficiency on Bungulla

4.1 *Weather dependant farming requires timeliness of decision making*

Four key operations pertain to annual grains production. These are seeding, harvest, spraying (boom application of herbicides and fungicides) and spreading (fertilisers and soil ameliorates such as lime and gypsum). Each are critically time dependant in that management decisions must be highly responsive to changes in environmental conditions to avoid significant losses in yield and / or quality. For instance, timely harvest is necessary to minimise the chances of rain and fire related losses. Autumn seeding is a little less time critical as seeding begins after ANZAC day and improvements in technology permit much of the crop to be sown into dry soil if necessary. However, autumn conditions will alter the rate and mix of the seeding program to some degree[6]. After trialling liquid fertilisers, the farm has predominantly used them since 2013. Liquids provide a number of benefits. They are operationally far more efficient to apply (at seeding or subsequently via boom or aerially), are better suited to the extended autumn droughts that have apparently become a feature of the local climate, liquid N is less acidic than granular N fertilisers and the form lends itself to the application of alkaline fertilisers that to create improved pH for emergent seedlings.

Furthermore, Bungulla's shift to a mainly liquid fertiliser program largely ties the seeding and fertilising programs together, although some fertiliser is applied post seeding using the boom. Boom operations are very dependent on weather conditions as these effect the efficacy of applied chemicals, which must be applied when crops and weeds are at their applicable growth stages.

4.2 Reliable machinery removes risk of loss of timeliness

Consequently, machines are thoroughly serviced at the end of harvest / seeding / spraying and rechecked before the next harvest / seeding / spraying. As reliable operation is critical to the business' success, these machines are used for below average hours for the industry before resale; for instance harvesters are resold at 1,000 hours (3 years) use. Harvesters, seeding rigs and boom sprays are supported logistically by other machines so they can work the maximum hours available during the operations' windows of opportunity.

4.3 Harvest and seeding operations at optimal logistical rates

The farm's harvest and seeding operations are highly efficient when considered from a possible machine work-rate perspective. The 12m width harvester can travel 10km/h implying a work rate of 12 ha/hr. This is achieved by ensuring a chaser bin is always available to take grain from the harvester so it does not stop operating. Of the $55/ha budgeted for harvest operation cost, the chaser bins account for around $5-6/ha and thus redundancy in chaser capacity is an important and cost effective tool in ensuring maximum harvester operational efficiency.

Similarly, seeder operation is also highly efficient especially since the swap to nearly all liquids fertiliser application in 2014 has permitted very tight logistical co-ordination and faster work rates. Sowing rates increased by 100ha/day to about 600ha/day (assuming good weather), implying that the sowing period has reduced by 3 days. This also increases the ability to respond to adverse weather developments. The farm regularly achieves the possible weighted average work rate between the 60ft (18.3m) and 40ft (12.2) seeders of just over 13ha/hr as the machines travel an average speed of 10km/h. The budgeted seeding operation cost, including support vehicles, is $35/ha.

These work rates include provision for necessary refuelling and loading.

4.4 Excellent machinery requires excellent staff to operate them and excellent self-directed staff reduce management complexity

These outcomes are also a function of a highly trained and stable workforce. There are five permanent staff and no casuals. Each employee has a specialised role for which they take management responsibility (e.g. farm manager, workshop, civil, transport, machine operation and, including Brad, business development / financial control). During seeding and harvesting all staff co-ordinate to ensure these tasks are completed in a timely manner.

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[6] For instance, this year dry season start conditions have resulted in swapping some canola for barley (Clarke, 2018).

Permanent staff create scope for continuous skill improvement. Staff turnover is very low which is indicative of a workplace with fulfilling career opportunities and excellent conditions. Since 2006 there have been two retirements and one planned departure (after completion of advanced pilot training). The Jones' view utilisation of their staffs' skills as sources of critical point failures as it take years to accumulate the necessary knowledge for efficient operation. That is, for staff to perform at optimal levels, they must have the necessary knowledge, tools and technologies to operate with. In addition, a system of positive feedbacks exists to engage and empower staff. First, the business objective is readily understood and easily communicated to all in the business[7] so that decisions are measured against it. Second, each staff member has managerial responsibility for a discrete area of the business. Third, profit based incentives (the formal business objective) are coupled with personalised soft incentives (e.g. leave, family care, access to facilities) so that these become the secondary objectives of the business, which further encourage high staff retention.

4.5 Web based platforms make the farm visible to all staff…

The farm uses four web based platforms to manage physical data (AgWorld (inputs) and My John Deer (machinery)), accounting data (Xero) and farm management (P2P Agri). Staff have access to AgWorld data on their iPhones as it is used to manage 'data for crop planning protection, nutrition and management' (AgWorld[8], 2018).

My John Deer data feeds into Agworld and Xero platforms and Xero will soon feed into P2P Agri. These four platforms monitor the farm's day to day performance by integrating data from below – e.g. soil mapping and yield data – and with data from above – satellite and drone (under trial) monitoring data.

A clearly understood business objective, a focussed grains only operation, a specialised, semi-autonomous and stable staff pool, sharp and soft incentives to align staff to the business objective, open sharing of data necessary to empower staff autonomy and provision of tools and training to carry out roles, collectively act to reduce management complexity.

4.6 Boom not at logistical optimum due to logistical complexity

A combination of the boom's comparatively high speeds, its variable application of chemicals, its multiple applications across paddocks and weather variability complicates estimates of its likely refuelling and reload times, and its possible locations. The boom has 'Weedseeker' technology mounted which identifies weeds by cameras[9] and applies herbicides only to identified targets. This can reduce herbicides application compared to a conventional boom by as much as 90% (currently 78% on average since its adoption). Current advances in camera recognition technology that identifies particular species and tailors chemicals to specific plants will further cut chemical use and costs, but may also increase logistical complexity as a greater number of tailored applications are applied. The boom is also used to deliver additional liquid fertiliser (N) to canola crops in June and applications of fungicides across crops.

4.7 Analysis of boom operation cost efficiency co-efficients

Boom spray applications remain below a practical efficient rate of 75ha/hr, which includes 8 minutes per hour for traveling and loading of the machine. That is, the 36m boom can travel

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[7] https://www.youtube.com/watch?v=R3S2DkNC7PI&feature=youtu.be
[8] https://agworld.com.au/index.php?p=blog/case-study-brad-jones
[9] Or preloaded satellite images as appropriate

at around 24km/h (87ha/hr), less necessary servicing time to achieve a work rate of 75ha/hr. At this work rate, the boom operation cost is $6.01/ha. This work rate is defined as 100% efficient, or has an efficiency coefficient of 1.

Table 2 presents the composition of the $6.01/ha operation cost. Labour is priced at the wage rate plus all overheads per hour. Fuel usage is 130L/h at a cost to the farm of $0.65/L. Depreciation is determined by the manufacturer's assessment of the useful life of the machine. Capital cost is the difference between the purchase and resale prices of machines. Note, the charging of a capital cost to the operation over the depreciation rate is an example of minimising exposure to a potentially negative event, in this case a lower than expected resale value. This protects the business' cashflow by ensuring ample available cashflow to purchase the next new machine; new machines minimise the probability of production losses from machine failure (new machines also embody the latest technological advances available from machinery manufacturers). Repairs and maintenance are a function of the number of hours the machine is used before resale and its maintenance history; fewer hours of operation imply lower maintenance costs. A margin is charged to account for the opportunity cost of the capital used in the operation of the machine. The margin is set using an internal rate of return 20% to calculate an hourly amount.

Table 2: Boom operating cost at an efficiency co-efficient of 1

	Labour	Fuel use	Depreciation	Capital Cost	R&M	Total	Margin	Total
Unit	FTE	Litre	Hour	Hour	Hour		Hour	
Unit, hour	1	130	1	1	1		1	
$/unit	40	0.65	118	90	40		78	
$/hr	40	84.5	118	90	40	373	78	450.5
$/ha	0.53	1.13	1.57	1.20	0.53	4.97	1.04	6.01
%, cost	9%	19%	26%	20%	9%	83%	17%	100%

Table 3 examines the impact of an additional 4 minutes of travel and 4 minutes of loading. Whilst the work rate may be reduced by 13.3% (an efficiency co-efficient of .87), costs will not rise commensurately by 13.3% to $6.81/ha. This is because additional loading time implies the machine is idle during this period and therefore less fuel is used and less depreciation, capital cost, R&M and consequently margin is charged at an hourly rate which is converted to a $/ha rate. Calculated cost rises to $6.50/ha (8.4% increase), or a loss of $0.50/ha.

Table 3: Boom operating cost at an efficiency co-efficient of .87

	Labour	Fuel use	Depreciation	Capital Cost	R&M	Total	Margin	Total
Unit	FTE	Litre	Hour	Hour	Hour	Hour	Hour	
Unit, hour	1	121	0.93	0.93	0.93		0.93	
$/unit	40	0.65	118	90	40		78	
$/hr	40	79	110	84	37	350	73	423
$/ha	0.62	1.21	1.69	1.29	0.57	5.39	1.12	6.51
%, cost	9%	19%	26%	20%	9%	83%	17%	100%

A typical paddock on the 10,000 ha Bungulla farm may have as many as 6 applications over a season, depending on where it is in the six year crop rotation cycle (typically, cereal,

cereal, break (canola, legumes or fallow)). Consequently, over 52,000ha is planned to be sprayed over the 2018 season. This implies that a consistent loss of 13.3% of operational efficiency in boom operation could cost the business around $25,000 over 2018.

Table 4 examines the impact of both reducing lost travel and loading times by 3 minutes, such that the efficiency co-efficient rises to .97, that is to 3% below its practical efficiency co-efficient of 1. An increase in the hourly use of the machine also increases the pro rata hourly charges such that costs are 1.9% above those at the practical limit to efficient operation. This implies that the consistent loss of 3% of operational efficiency in boom operation could cost the business around $5,000 over 2018. An improvement from .87 to .97 would result in a $6.51 (Table 3) - $6.12 (Table 4) = $0.39/ha benefit to the farm for each of the 52,000 ha sprayed.

Table 4: Boom operating cost at an efficiency co-efficient of .97

	Labour	Fuel use	Depreciation	Capital Cost	R&M	Total	Margin	Total
Unit	FTE	Litre	Hour	Hour	Hour	Hour	Hour	
Unit, hour	1	127.83	0.98	0.98	0.98		0.98	
$/unit	40	0.65	118	90	40		78	
$/hr	40	83	116	89	39	367	77	444
$/ha	0.55	1.15	1.60	1.22	0.54	5.06	1.06	6.12
%, cost	9%	19%	26%	20%	9%	83%	17%	100%

5 Wi-Fi trials creates the basis for applying technology to ensure the boom's .97+ operational efficiency

5.1 Bungulla Wi-Fi trials part of DPIRD and GRDC cross wheatbelt trials…

In 2018, Wi-Fi coverage was under trial across 20% of the farm as part of a DPIRD[10] and GRDC[11] joint project to create digital tools and methodologies to minimise cost and increase profitability through increased efficiency. The project is trialling the use and further development of open source software and technology so users are not locked into proprietary systems and so that they retain ownership of their data. Besides openness, the project also focuses on using technology that is available right now and is fit for purpose for growers. It also focusses on identifying the lowest cost options so that more sensors can be deployed across a given farm area.

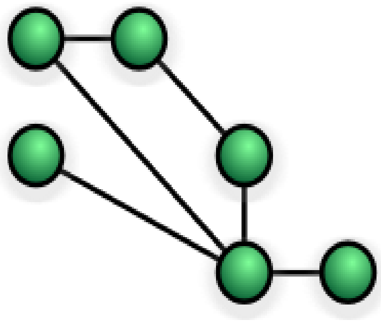
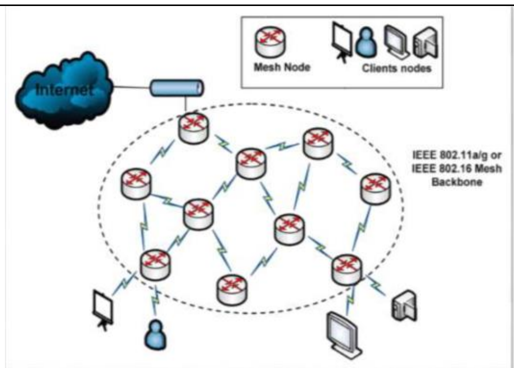
Furthermore, connectivity across much of the broadacre landscape is either poor and intermittent or non-existent at present, unlike mature markets such as the US. This implies that the lowest risk – from a loss of service perspective – are on farm (or edge) computing solutions that capture and process data (small data as opposed to big data) which is processed and uploaded by farmers at their discretion. Indeed, Bungulla invested in three bi-directional antennas trained on Telstra's mobile tower in Tammin to create high speed data transmission to/from the farm. Their cost has not been considered in this analysis as the boomspray analysis discussed above is configured as an edge computing solution.

[10] WA Department of Primary Industries and Regional Development
[11] Grains Research and Development Corporation

5.2 … low cost technology trial …

Bungulla is one on the farms hosting project trials. DPIRD is also creating digitally connected operations at its Merredin and Katanning research stations for trial and demonstration purposes. The Bungulla trial system consists of receivers mounted on top of the workshop and silos. It employs an open source 2.4 GHz transceiver Meshbee network. The firmware can be customised and set up as a mesh (or star/tree) topology. This provides the full coverage across the farm needed to track machines in order to optimise logistical efficiency. Logistical efficiency is particularly important to grain growing because of the high degree of machinery that is used. That is a WiMesh system is highly suitable to Bungulla's grains operation particularly from a logistical perspective.

Figure 4A illustrates a partially connected mesh network topology in which not all nodes are connected to each other. The data signal from the singly connected nodes would be lost if either of these failed. Figure 4B illustrates a full mesh topology in which each component is connected to the other components. The fuller the connections between components, the higher the volume of data traffic that can be transmitted; moving machines will create a steady and heavy data flow. Also if one component fails, data transfer is not affected. This means that the topology can be modified and expanded without impacting on data transfer.

<table>
<tr><th>Figure 4A: Partially meshed topology</th><th>Figure 4B: Highly meshed topology</th></tr>
<tr><td></td><td>
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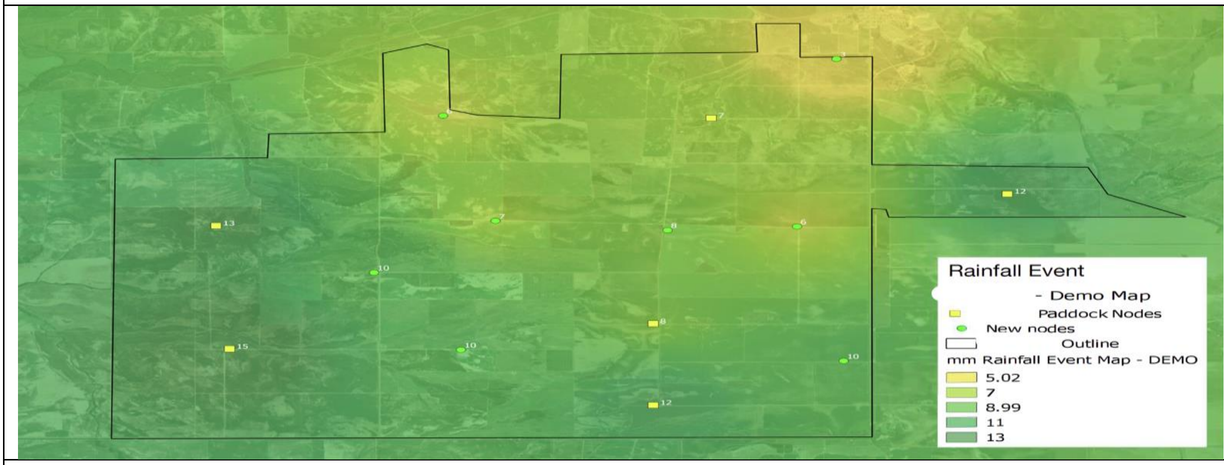
A highly meshed system such as Bungulla's implies the need for a power supply beyond stand alone batteries. A solar panel and battery is shown in figure 5 as the power source for a node operating on Bungulla.

Figure 5: Tripod with electronics box, sensors and solar panel

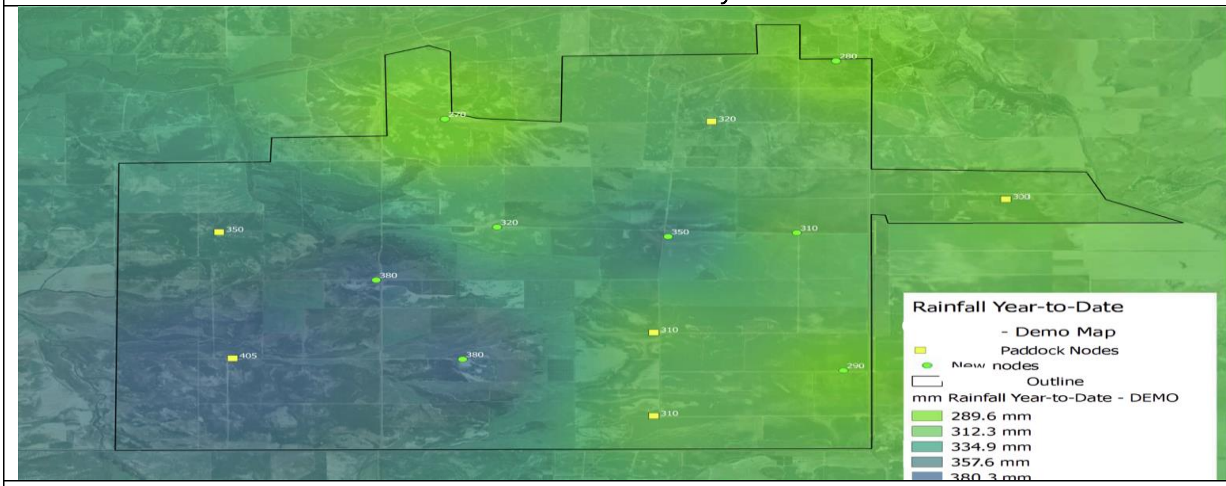
5.3 … with weather related sensors to evolve into cost effective data to augment the farm's work flow process…

The receivers are linked to nine remote weather stations around the farm which are in turn linked to moisture probes. Successful implementation of the technology to generate accurate estimates of soil moisture availability will allow for better utilisation of existing soil map, rainfall and yield data to generate better water use efficiency – a key performance measure of the amount of grain produced per mm of rainfall and water use efficiency per dollar of profit, a more accurate measure of business performance. Figures 6A, 6B and 6C are rainfall maps of the beginning season gathered from another farm using the same technology. 6A shows a recent rainfall event; 6 B shows rainfall to the year and 6C shows rainfall the previous month.

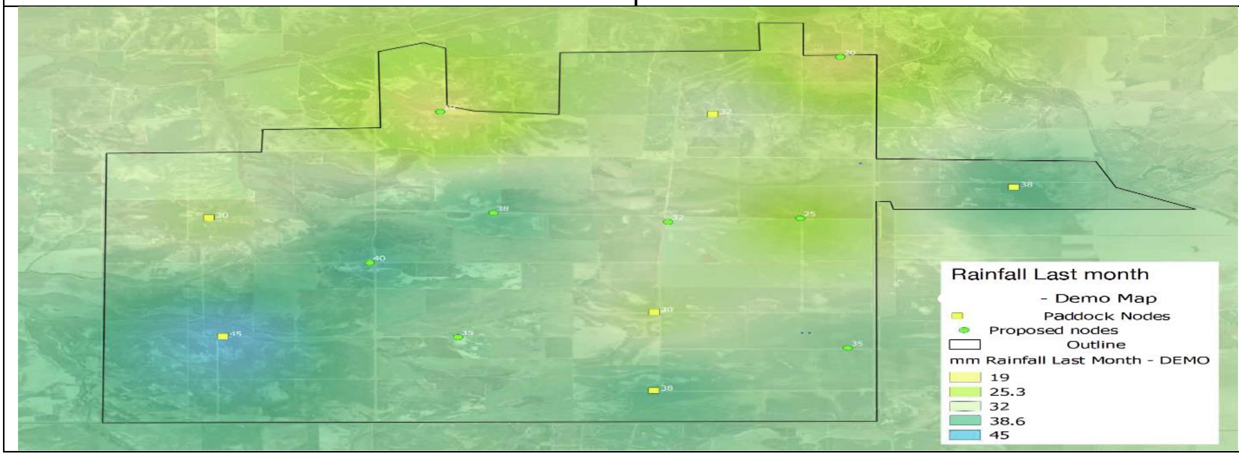
6A: Recent rainfall event



6B: Rainfall to the year

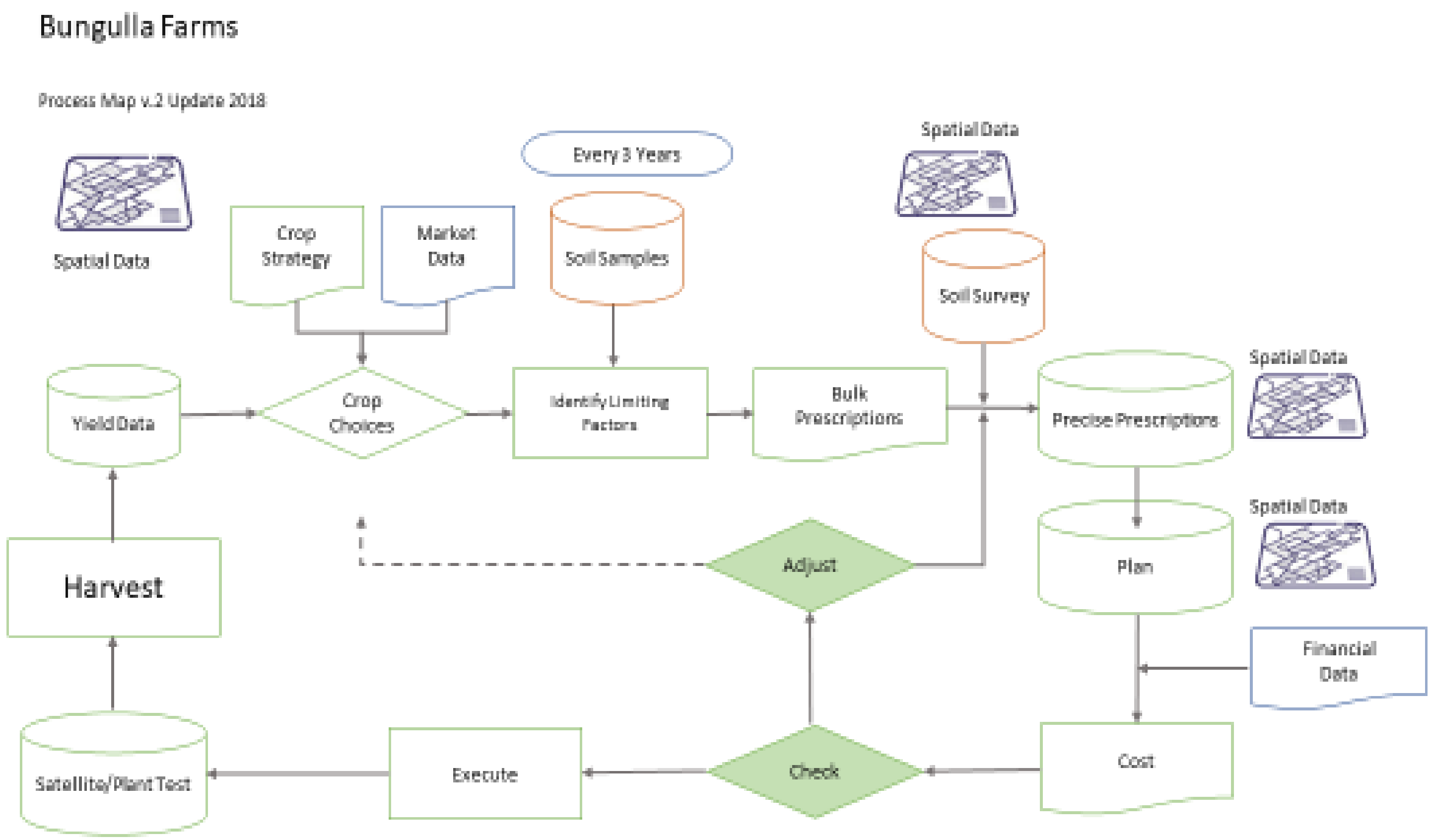


6C: Rainfall the previous month



So far the project is a data base with associated infrastructure with a vision to begin the season with additional knowledge to further modify the workflow program in response to data analysis. The context of this vision can be seen by examining figure 7, Bungulla's work process map.

Figure 7: Bungulla Farms work process map



The plan's execution commences with seeding in April. Either sufficient moisture or a calendar date (dry seeding) will signal the beginning of seeding.

Satellite plant testing begins in July. Satellite images are produced every 7 days. If the images are not clear, a background algorithm creates a predictive growth rate. The program recalibrates itself with the next clear available image. As 2018 is 1st year use, the technology not used to its full capability, as primary goal is to trial and build confidence in its use. It is currently being used as a reference point in that images are used to identify where the farm's soil or agronomist consultants should look. Their investigation is informed by the farm's soil mapping and soil test data to gain a clearer picture as to the why a crop problem is occurring. Currently, drone technology is also under testing to further increase problem identification accuracy. In the future it is hoped this technology will be used for select densification as the drone will identify specific species of weed using machine learning and camera technology.

After harvest, yield data is examined for production losses / gains and matched to soil mapping data to build understandings of why these anomalies occurred. This information is used to augment the next year's crop strategy, which is part of an existing rolling three year rotation strategy. This may result in a slight adjustment in crop choice.

The next step of examining market data has a small influence over crop choice. It is incremental only because the largest risks in the system are production related. For instance, there are currently opportunities in the hay market and while the system can be tweaked to incorporate more hay, it will not be to the detriment of the overall production plan's focus on building long term cost reductions.

Soil testing data, from wherever the bulk of these are taken from at the time, is overlaid with spatial data and incorporated into the analysis process. This data provides the confidence that the system has the nutritional requirements it needs. This process informs the bulk prescriptions needed, such as liming, gypsum and potassium for the following crop. Spatial data is further used to refine these prescriptions for specific areas of need. This information is synced into the farm plan by the end of January / beginning of February.

Inputs costings are then added and any further modifications to the plan are made. For instance, it may be more expensive to take hay from one paddock than another, so this costing information is used to modify the plan.

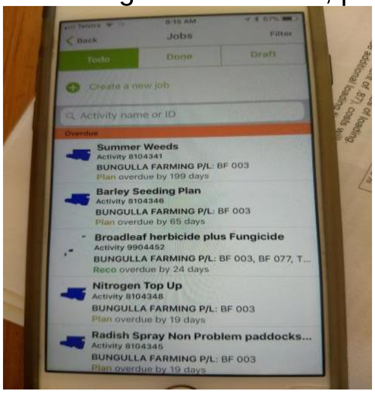
By the end of March, all prescriptions are loaded into the machines and all soil amelioration is completed. Everything is checked before executing (seeding) the plan.

5.4 … this will include logistical co-ordination…

Another key benefit of adopting Wi-Fi across the farm is the opportunity to further invest in relevant sensors and extend the system to improve boom logistics as described in section four above. Collation of sensor data in the boom and support vehicles' chemical and fuel tanks when juxtaposed with location can help with the on ground co-ordination; wind speed and other weather and soil data will help to guide decisions as to the boom's optimal deployment. All data produced by Bungulla's system is stored on the providing company's server in the Cloud. It is accessed via a single visualisation dashboard (internet browser). Data is displayed in user friendly phone dashboards, much like the jobs data presented in figure 8A and 8B.

Figure 8A: Bungulla Farmhub home page

Figure 8B: Bungulla Jobs to do, paddock



High data collection and collation costs can infer that it is not worth doing so. Thus considerable parts of a business' cost structure remains opaque and that which is not measured is unable to be improved upon. The lower the cost of the IT to collect this data, the greater the granularity of data that can be usefully collected to identify the next round of potential efficiency gains to drive down the cost curve.

5.5 … and value chain formation…

Better data collection (and connectivity) also implies potential opportunities for improved value chain creation / integration. These include provision of services associated with grain, such as quality, timeliness and attributes that increase animal feed to conversation rates. They may also include provenance and sustainability assurance. This is particularly pertinent to Bungulla as the enterprise has developed feed market opportunities in recent years and is keen to develop overseas niche markets for its grains. Central to its ability to create value for customers has been its investment in state of the art silos, grain testing equipment, bulk storage and transport to deliver as per customers' requirements.

6 Wi-Fi $/ha cost and NPV from efficient boom operation

Table 5: Net Present Value of boom logistical efficiency improvement from .87 to .97

All ha sprayed:	52,387						
All ha Wi-Fi	10,328						
Year			Year 1	Year 2	Year 3	Year 4	Year 5
Revenue, all ha sprayed, $			20,448	20,448	20,448	20,448	20,448
Cost, all ha Wi-Fi, $			3,470	3,470	3,470	3,470	3,470
Gross margin, $			16,977	16,977	16,977	16,977	16,977
Discount rate		20%					
NPV, $		24,236					
		-21,690	16,977	16,977	16,977	16,977	16,977
		73%					

The fully installed cost of the hardware and software components of the Wi-Fi system is $2.10/ha and the annual operation cost of the system is $0.34/ha. 2018's cropping program (including fallow) is 10,328ha. Thus the total capital cost is $21,690 (10,328 x $2.10), to which is added $3,470 (10,328 x $0.34) per annum for the five years of the system's useful life. The benefit per ha of an improvement in the boom operation's logistical efficiency from

.87 to .97 is $0.39/ha. Assuming the same number of hectares are sprayed in the four years following 2018’s 52,387ha spray program, the benefit (cost saving) is $20,448 (52,387 x $0.39) per annum. Table 5 indicates that the Net Present Value (NPV) of this cost saving is $24,236 at a discount of 20% and the Internal Rate of Return (IRR, the discount rate at which NPV is zero) is 90%.

The annualised value (NPV / 5 years) of the Wi-Fi is $4,847 and the payback period is 1.28 years.

7 A disciplined pattern of trialling innovations to achieve efficiencies, reduce risk to cashflow and lift returns

7.1 A consistent pattern of innovation trialling and adoption…

The previous description of a small scale trial to learn from doing and so identify unanticipated problems and opportunities, is consistent with a pattern of innovation development and adoption at Bungulla.

Trialling innovations have resulted in many changes across the farm resulting in increases in TFP. Table 6 provides a snapshot of some of the key innovations in business activities and practices between 2007 and 2018. It illustrates the magnitude of the changes over the past decade.

Table 6: a comparison of key business activities and practices on Bungulla, 2007 and 2018

2007	2018
Yield target: T/ha	Profit target: Net profit / ha
Experienced based rule of thumb decision making	Experienced based rule of thumb decision making informed by data based evidence: independent advisors, digital data sets, structured trials
Largely uniform applications of chemicals, fertilisers and soil ameliorants	Variable applications of chemicals, fertilisers and soil ameliorants
Granular fertiliser applications	Nearly all liquid fertiliser applications
All grain exported via CBH	Variety of export and domestic market channels
No on farm storage	Extensive on farm storage
Transport to local receival bin only	Continuous haulage for two way efficiency
???	Expanding number of trials across a range of farm activities (IT, machinery, seed varieties, soil amelioration)

7.2 Foundation data of soil analysis, yield records and weather observations…

A key foundation investment was the across farm soil analysis carried out in 2007. This consisted of electromagnetic soil mapping to identify changes in soil salinity, texture and moisture, and gamma radiometric spectrometry used to indicate soil parent materials. Together, these provided the initial data, when matched with yield and weather data, and identified that key limits to profitability were soil pH and weed loads. These data have provided the base for subsequent hundreds of trials that have been undertaken (Field, 2016). The trials have included testing crop varieties, fertiliser application, variable rate technology and row spacing at sowing.

7.3 … resulting evidence for a swap to practices better suited to soil and climatic conditions…

Importantly, these early trials identified that seeking to maximise yield is unlikely to maximise profit in an (increasingly) uncertain climate, especially when coupled with inherently poor soils not suited to high protein wheat production which is the farm's main crop. Fertiliser use was subsequently trimmed, tailored and applied variably across soil types so as not to place yields and quality at risk in the event of adverse events, to address sub soil constraints and target application to areas of highest benefit. For instance, 2018's nitrogen application is reflective of the top 25% of L3 Planfarm Benchmarked producers. Although the 10 year average wheat yield (1.97T/ha) is less than the district average[12], the resulting cashflow is more stable compared to what it would have been with higher fertiliser application rates. Importantly, the margins improved due to reduced fertiliser costs and few, if any, quality downgrades from weather events. Steady cashflow and improved margins permit a steady pattern of capital improvements on the farm.

7.4 … and creation of new market opportunities…

Lower protein wheat and the farm's proximity to intensive feed markets around Perth provided the opportunity to alternative routes markets from the export oriented CBH network. A $690,000 investment into a 9,000 tonne silo and storage complex gives the farm the operational flexibility to deliver to quality grades without using CBH facilities for testing, handling, blending, insect and moisture control. Coupled with backhaul opportunities, grain handling costs have been reduced from around $30/T to about $12/T for the around 60% of the crop not handled by CBH. The computerised 5,000T section of the complex was completed in 2014 to complement the feed sales trials from existing bulk storage. Further bulk storage has been added and trials of new low cost bulk storage options are ongoing. Importantly, CBH receival bin interruptions are not able to interrupt harvest and storage also implies that poor weather is less of a constraint as the silo complex can control for moisture levels. This increase harvest operational efficiency and reduces the risk from harvest damage to crops.

7.5 …and further changes in practices to deal with profit constraints…

A further yield penalty is borne in big production years from chemical fallowing across 8 – 15% of the property each year. Chemical fallowing was introduced to manage weed burdens on problem areas, particularly on soils with poor pH, and to provide a rotational break to reduce cereal crop root and fungal disease. Chemical fallowing provides an opportunity to manage weed resistance by applying a broad spectrum of herbicides and carry out a range of soil amelioration practices such as liming (to correct pH), gypsum application (soil structure), mould board ploughing (weeds and non-wetting soils), deep ripping (soil compaction) and civil works that improve operations such as removing fences, squaring paddocks and filling in old dams. Reducing production constraints leads to improved soil biology, plant available moisture, crop performance and operational efficiency. Fallowing also increases nitrate availability to the subsequent crop, resulting in a higher yield

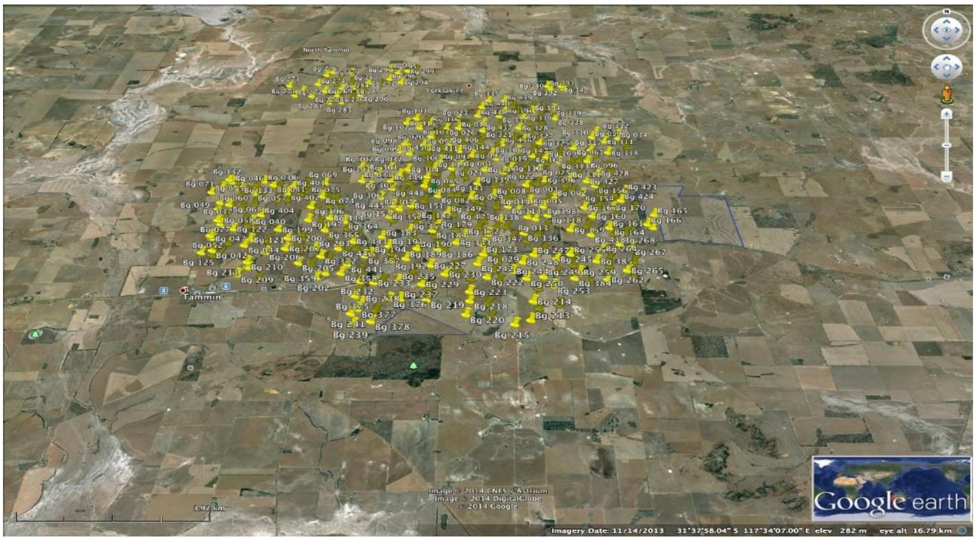
[12]Planfarm Bench mark 2016 average yields: M3 / 2.13T/ha (average); M3 / 2.61T/ha (top 25%); L3 / average (1.68); L3 / 1.93T/ha (top 25%)

and quality for a corresponding lower nitrogen application. Canola, the most profitable crop, is typically grown after a fallow.

7.6 …coupled with continuous monitoring and analysis….

Soil nutrition and health is closely monitored by a steady increase in the number of annual soil tests carried out. Currently, there are over 570 test sites (figure 9) and the whole farm is sampled on a three year rotation. These tests indicate steadily improving pH, and provide the data necessary to adjust fertiliser application to ensure adequate crop nutrition and inform the soil amelioration program. The tests include microbial DNA as a measure of overall soil biology.

Figure 9: Soil testing sites, Bungulla Farm, 2018



The use of hybrid canola captures canola's rotational and profit advantages, but is less risky in poor seasons. However, its expense stimulated co-investment with a Queensland engineering firm in 2015 to develop and trial a singular sowing machine for canola. Thus far, sowing rates has decreased to .6kg/ha (Clarke, 2018), compared to a recommended rate of 1.9 – 2.6kg/ha for optimal plant density by DPIRD[13] using conventional technology (see also Seymour, 2014). As the farm was already using less than the recommended seeding rate, the savings are slightly less than 1 kg/ha, or about $25/ha. An additional margin from a 5% increase in yield results in a total margin increase of $50/ha. 2,300ha of canola was planted in 2018.

Table 7 presents a snapshot of selected innovations and indications of the returns from them.

With the exception of the last row, the above innovations facilitate cost reductions by increasing the ratio of outputs to inputs. That is, they are improvements in the business' TFP. Improvement in sales efficiencies from silo use, is a lower cost means of financing working capital by sale of the silo's ability to 'carry' stock and the purchaser's confidence in the business' ability to deliver as promised.

13 https://www.agric.wa.gov.au/canola/canola-seeding-rate-information

Table 7: Timetable snapshot of selected innovations

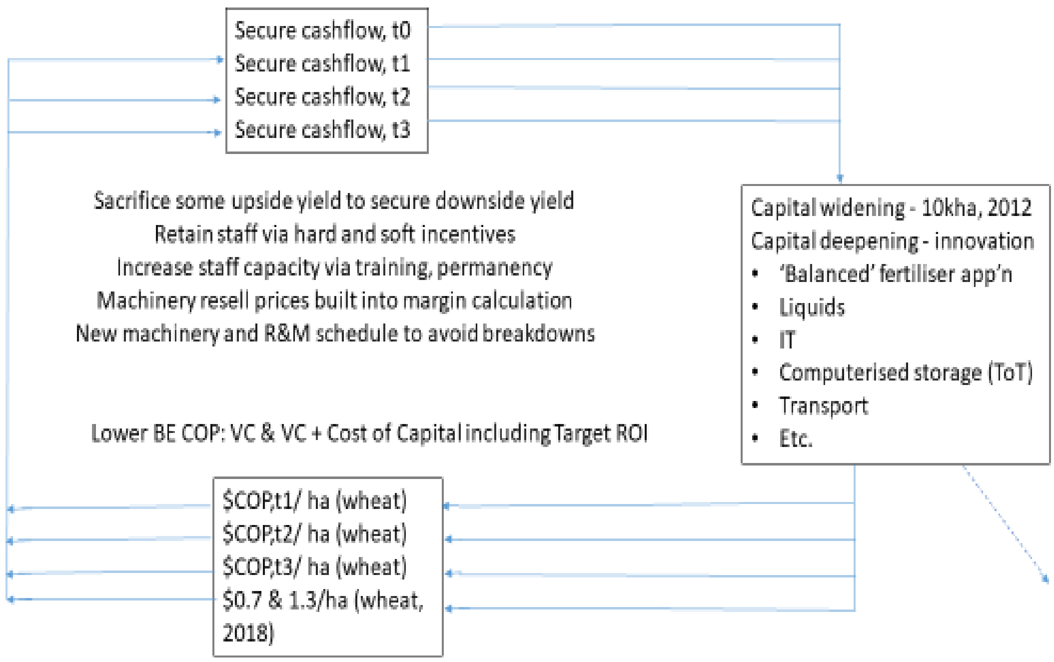
Innovation	Year trialled	Year fully adopted	Benefit description	Value estimate
Extensive soil testing sites	2008 (? sites)	2018	Currently ~ 570 sites provide extensive data to monitor soil conditions	
Variable rate technology	2008	2010; ongoing	Cost reductions in fertiliser, lime and chemicals applications	1 year payback
Fallowing	2008	2009	Weed control efficiency / weed herbicide resistance strategy; soil amelioration and civil programs	
Weedseeker	2009	2009	Greatly reduced chemical application	2 year payback
Liquid fertiliser adoption Liquid calcium / P / K (DKP, Optima)	2012	2013	Operational efficiency (boom and aerial), better suited to climate, less acidic N Corrects pH around merging seedling	11.3% improved ROI; 17% operational efficiency improvement
Hybrid canola seed use			Early season vigour and finish; less susceptible to poor seasonal conditions	$25/ha
Canola seed singulation	2015 -	Under development	Greatly reduced seeding rates of expensive hybrid seeds	$25/ha, gross saving
9,000T silo complex	2012-13 direct marketin g	2014	Operational, logistical and sales efficiencies, able to meet contract specifications	20% ROI
Backhaul / continuous trucking	Ditto	2014	Ditto	20% ROI
Wheat varieties better suited to feed production	Under trial	Under trial	Lower protein wheats produce more energy, requiring less N which lifts yields and places crop under less climatic risk i.e. less risk from cliff face protein effect	
Greater proportion of hedged prices for exported grain (swaps) and local sales (forward contracts)			Less production variability implies greater opportunity to hedge larger proportions of the crop if opportune.	

Table 7's last 'innovation' is a consequence of the business' lesser production variability and an increase in the business' terms of trade (the ratio of price of outputs to the price of inputs) as it locks in higher hedge prices for a greater proportion of the crop. The ability to negotiate better purchase terms because of scale is also a terms of trade advantage.

2018's all in wheat crop cost $/ha stands at $287, which translates to $192/T, $144/T, $115/T at yields of 1.5T/ha. 2T/ha and 2.5t/ha respectively.

Figure 10 represents this process diagrammatically. Securing cashflow permits investment (e.g. securing yields in poor years, staff retention, staff capacity, locking in machinery resell values and avoiding machinery failures) into capital widening (scale) and capital deepening (increasing the ratio of capital to other inputs). These lower the cost of production per hectare, which increases the flow of secure cashflow, which in turn increases the level of investment into new innovations.

Figure 10: Bungulla Farms process of securing cash flow to finance innovation down its cost curve



In summary, Bungulla's use of a suite of precision agricultural (PA) technologies may be thought of as closer to the 'decision agriculture' end of the IT spectrum as described by the Australian Farm Institute's report on Smart Farming (AFI, 2016). The AFI defines decision agriculture as 'analysis of digital farm data along with other relevant digital datasets such as soils and environmental data which leads to improved data driven decision making by farmers and enables the use of data driven technology' (p.5).

Perret et al (2017) estimated that a 25% increase in GVP (the actual production output) across agriculture if decision agriculture were fully implemented. In grains the estimated increase in GVP was 51% and its estimated productivity improvement tallied nearly 17% as indicated in Table 8:

Table 8: Productivity improvements and corresponding increase in GVP for cropping sectors

Practice	Productivity improvement modelled (%)	Increase in GVP (%)
Fallow preparation	0.98	2.98
Crop rotation	5.00	15.24
Planting	3.28	10.00
Crop nutrition	2.85	8.68
Crop protection & weed control	0.26	0.79
Labour saving	2.50	7.62
Yield forecasting	2.00	6.10
Total	**16.86**	**51.41**

Source: Perret et al (2017)

8 Discussion

8.1 Critical importance of safeguarding business cashflow from volatility and innovating down the cost curve to protect business and industry net profit from structural loss of competitiveness

As commodity producers, farmers have little control over their terms of trade. Grain farmers are large users of imported inputs, and in WA and SA they are predominantly exporters, so their terms of trade are heavily influenced by exchange rates. ABARE data of terms of trade (Table 9, column 2) are aggregated across the rural sector and these indicate a slightly adverse outcomes over much of the period since 1990, but with recent improvements which probably reflect high cattle, sheep and wool prices.

Similarly, the index of wheat prices paid to Australian farmers (column 3) also indicate price increases over the period, but note the drop in the last year's data. World trade volumes in wheat (WA's largest agricultural export) have grown by 40% between 2010/11 and 2016/17 (column 4). However, Russia and the Ukraine's exports (the largest Black Sea producers) have grown by 450% (column 5) and they accounted for 26% of world trade in 2016/17 (column 6). Global wheat stocks have grown (column 7) and export prices in USD have correspondingly fallen (columns 8 & 9). Column 10 indicates that falls in the USD / AUD have mitigated some of this USD price fall. However, much of grain production's inputs are also imported.

Table 9: Selected data, ABARES 2017

1.	2. ToT	3. Wheat price index	4. World wheat trade volume, MT	5. Russia / Ukraine exports, MT	6. Russia / Ukraine, % of world trade	7. Global closing stocks	8. Export price (Gulf), USD	9. Aust. price (ES), USD	10. Aust. Price (ES), AUD
97–98	100.0								
98–99	94.9								
99–00	91.1								
00–01	97.4								
01–02	108.1								
02–03	101.0								
03–04	95.2	109.1							
04–05	92.4	99.6							
05–06	91.7	102.5							
06–07	95.7	122.4							
07–08	91.4	197.2							
08–09	88.3	142.1							
09–10	88.3	110.4							
10–11	96.2	130.1	126	8	7%	23	317	280	345
11–12	93.3	114.6	145	27	19%	20	299	249	290
12–13	95.0	158.3	141	18	13%	20	348	327	336
13–14	98.2	159.8	157	28	18%	16	317	282	329
14–15	103.9	151.7	153	34	22%	20	266	252	295
15–16	109.2	140.1	166	43	26%	27	211	220	281
16–17	111.3	125.0	176	46	26%	32	197	190	265

Rabobank (2018) forecasts total Black Sea (Russia, Ukraine, Kazakhstan and the Danube River countries) ‘wheat exports to increase by a further 18 per cent to 45 per cent by 2030/31.’

Table 10: Costs of wheat production in Ukraine and Australia*

Cost component ($/T)	Ukraine	Australia*
Wheat yield (t/ha)	3.35	1.82
Seed	42	27
Fertiliser	181	90
Chemicals	74	110
Diesel	54	15
Labour	25	11
Variable operating costs	376	253
Direct salary and tax	10	43
Land	60	80
Total costs ($/ha)	446	376
Total costs ($/t)	133	207

* Weighted average across regions (AEGIC, 2015a)

AEGIC (2016) found that a combination of higher yield growth rates and lower labour costs, result in Russia and Ukraine's lower cost of on farm wheat production ($AUD121and $AUD133 respectively) compared to Australia ($AUD216), further aided by comparatively large currency depreciations. Table 10, illustrates the impact of the Ukraine's much higher yield on its $/T production cost.

Infrastructure investments and cheap freight rates also add to the region's competitiveness and Rabobank (2018) expects that although currency and freight rates will shift in Australia's favour, these will not enough to compensate for region's lower cost base as evidenced by Table 11, AEGIC's 2016 estimation of total Russian costs of wheat delivered to port. Ukraine costs are similar (AEGIC, 2015).

Table 11: Estimated total cost of delivered wheat to port, Russia and Australia (2016)

Cost component ($/T)	Russia	Australia*
Cartage to bin	3.46	7.80
Storage	5.13	9.00
Up country handling	9.21	18.40
Transport to port	15.52	26.70
Handling at port	22.19	13.10
Shipping	0.19	6.80
Levies	.10	2.80
Supply chain cost	55.79	84.60
Production cost (wheat)	121.16	216.15
Total costs ($/t)	176.95	300.75

AEGIC (2016b)

Grain from the region is finding its way into price sensitive traditional Australian markets in South East Asia, despite Australia's freight advantage to the region. CBH CEO Watson reported in June 2018 that Black Sea wheat was displacing WA wheat in SE Asia at a price advantage of $AUD40T (Brammer, 2018). CBH aims to cut $100M from its operation costs as soon as possible (Brammer, 2018), which equates to $10/T assuming a 10MT crop. Thompson (2018) reported that 'Internal CBH forecasting shows demand growth in Australia's contestable markets, the Middle East, the subcontinent and Asia, being outstripped by growth in global wheat production led by the Black Sea and Argentina'.

Clearly a much lower AUD/USD exchange rate may only provide part of a solution to pressure on farmers' profits if current trends continue. AEGIC recommended several responses in addition to greater productivity (cost reductions) along supply chains. These include ensuring delivery of grain qualities and delivery packages that create more value for customers (moving from supply to value chains and enhancing Terms of Trade / securing market share) and R&D, with extension, to drive down unit costs at farm level; that is increase TFP at farm level.

However, many famers do not have access to the capital required to gain scale and embodied technology in new machinery. They also do not the capital or the training for a structured, data driven approach to innovation; without training, attempting to incorporate these technologies may increase managerial complexity. Therefore, public investment into training to develop farmer IT capacity to use lower capital cost on farm Wi-Fi **may** increase the returns from data driven farming. It could also be the start of a strategy of an increased adoption of evidenced based practices.

Indeed, Jackson and Malcolm (2018) found that on farm trials that generate site specific validation of investment opportunities (in this case with respect to adoption of pasture species) is far more important to increasing the rate of adoption than the supply of external (input suppliers and government) information. These issues are explored in greater depth in this series of subsequent case studies on farmer adoption of agtech.

A recent spate of farm consolidation in the WA wheatbelt may also imply that farmers with the necessary resources to adopt these technologies may be so busy integrating their new holdings into their existing businesses, that they lack the time to develop the necessary skills and strategic outlook to perceive value from them. Again, this implies that large productivity gains may be available from targeted training that addresses management complexity by building business decision making skills, as well as trialling that addresses issues of technical validity.

Lastly, organisation and time management training that drives farm level TFP is also required for farmer integration into developing value chains (Kingwell et al, 2014).

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