Smarter Irrigation for Profit

Monitoring and Evaluation

Economic Report

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George Revell and Jon Welsh, Ag Econ

Smarter Irrigation for Profit Phase 2: Monitoring and Evaluation

Client: Cotton Research and Development Corporation (CRDC)

Prepared by: Ag Econ

Namoi Valley, New South Wales

admin@agecon.com.au

George Revell +61 447 543 860

Jon Welsh +61 458 215 335

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1. Executive Summary

The irrigation industry is under significant and increasing pressure to adopt water-efficient practices to improve productivity. Modern irrigation technologies are designed to decrease irrigation water use and at the same time deliver significant gains in crop yield thereby contributing to both water and food security.

Smarter Irrigation for Profit Phase 2 (SIP2) was established to increase farm productivity and profit in the cotton, dairy, rice, grains, and sugar industries, by developing new irrigation technologies to increase Water Use Efficiency (WUE).

As part of the SIP2 monitoring and evaluation (M&E), 19 economic case studies were developed to better understand the implications of SIP2 research for farm profit, water use efficiency and changes in productivity. This report summarises the case study results, and provides further analysis on single-factor productivity, multi-factor productivity, and emissions intensity measurements to evaluate the SIP2 program against the target of a 15% productivity benefit for cotton, rice and sugarcane production through precision automated systems.

The key findings are summarised below:

- Among cotton irrigation technologies and systems, single-factor productivity changes varied. The largest gains occurred in labour productivity (average 228%), energy (11%) and water (11%). These were offset by a reduction in capital productivity (-6%) resulting in an overall multi-factor productivity gain of 5%.
- Automation in bankless channel rice production achieved high single-factor productivity improvements for labour (567%) with more modest but still significant gains in water and energy productivity (11% each). When combined with the increased capital base associated with automation, multi-factor productivity increased by 9%.
- Automation and system selection in sugarcane irrigation case studies uncovered reduced productivity resulting from the SIP2 focus on extension attributes of under-irrigation and crop yield marginal benefits. However, switching from big gun to furrow showed a 30% increase in multi-factor productivity with decreased labour productivity (-50%), being offset by increased water productivity (9%) and increased energy productivity (602%). Automating furrow irrigation saw large improvements to multi-factor productivity (165%), with decreased capital productivity being offset by improved water productivity (33%), labour productivity (400%) and energy productivity (65%).
- Grains scenarios resulted in the highest average multi-factor productivity gain of 127% of all industries. These were driven primarily by increased revenue generation from irrigation scheduling, livestock-related dual-purpose crops, and wheat for grain and hay production. These results proved sensitive to water price assumptions.
- A consolidated summary of all SIP2 research across the cotton, rice, sugarcane, and grains industries revealed a total average water productivity increase of 40% (with industry averages ranging from 5% to 133%, median 11%) and an average multi-factor productivity gain of 50% (ranging from 5% to 127%, median 35%).
- In regards to the specific target of 15% productivity gains from precision automation in cotton, rice and sugarcane (i.e. excluding research not related to precision-automation) the analysis found an average water productivity increase of 18% (range 11% to 33%, median 11%) and an average multi-factor productivity increase of 59% (range 5% to 165%, median 8%).

- Not all sites and technologies were assessed to have achieved the targeted productivity gains of 15%; however, it should be noted that not all optimisation and learning sites collected all the relevant productivity data, so conservative estimates were made based on researcher or grower estimates. As such, the findings of this report should be viewed in the context of the small data sets and necessary use of assumptions. In some cases, a lack of data impeded an economic evaluation for participating sectors. Future research objectives and outcomes should be supported by the collection of relevant data across all underlying research activities, including the baseline data collection. Such data collection should be specifically included in research outputs and budgeted at the start, as once contracts are signed leverage is almost impossible, especially with large multi-party applications. Funders should consider requiring data collection for economic analysis as a mandatory component of all funding applications. This will help to ensure a robust evaluation against stated research objectives, and an assessment of the research value proposition to support extension. This would also be supported by the development of an economic framework as part of project or program planning to inform data collection.
- The productivity findings of this report relate to the specific system, season, management, and climate dynamics of the underlying farms. Analysis should be conducted for individual circumstances prior to investment.
- Finally, the potential trade-off between single-factor productivity elements highlights the importance of evaluating climate adaptation approaches (such as conversion to new water-efficient irrigation technologies) in the context of wider climate change mitigation strategies (such as reduced greenhouse gas emission) to optimize both economic and socio-environmental outcomes. From this analysis, systems and technologies aligned with improved water use efficiency and lower emissions intensity (from reduced irrigation energy use) included: applying automation sensors and crop modeling across cotton, sugarcane, and rice sectors, moving to furrow irrigation from big gun application in sugarcane, and increasing farm output with less water in irrigated grains.

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3. Background

Water use in Australian agriculture

Irrigated agriculture contributes to Australia's agricultural and regional economic output. While Australian agriculture has historically been a global leader in water use efficiency (WUE), water continues to be a limiting factor in agricultural production. Climatic trends have decreased effective rainfall in eastern and southern agricultural regions, and these trends are only expected to intensify with time. Furthermore, water trading has increased competition for scarce water resources, particularly in the Murray-Darling Basin, further driving up water prices. In addition to economic considerations, water use is also increasingly scrutinised from environmental and social perspectives. Identifying smarter irrigation technologies and management practices to improve WUE helps irrigators and industry build sustainability credentials with an increasingly socially and environmentally aware global consumer. To remain competitive, if not viable, in the long term, Australia's irrigated agriculture industries must continue to improve WUE.

The Smarter Irrigation for Profit program

Smarter Irrigation for Profit Phase 2 (SIP2) was a Rural R&D for Profit (RRD4P) program led by the Cotton Research and Development Corporation (CRDC) in partnerships with Dairy Australia (DA), Sugar Research Australia (SRA), AgriFutures, and Grains Research and Development Corporation (GRDC). SIP2 received funding through the Department of Agriculture, Water and the Environment, the participating research and development corporations (RDCs), and the research organisations responsible for project delivery.

The objective of the broader RRD4P program was to realise productivity and profitability improvements for primary producers. In support of this, SIP2 was established with an objective to improve the profit cotton, dairy, rice, grains and sugarcane irrigators, building on the research, development and extension (RD&E) undertaken as part of SIP1 (2015–2018).

The SIP2 objective was underpinned by three economic outcome indicators:

1. 20% increase in water productivity on SIP2 optimisation and key learning sites.
2. Economic analysis of new precision irrigation technologies reports 10% increases in water productivity among participating cotton farming enterprises.
3. Economic analysis of precision automated systems for cotton, rice and sugarcane reports expected productivity benefits of 15%.

SIP2 sought to achieve these outcomes by focusing on practical, cost-effective strategies to improve the water productivity of Australian cropping and pasture irrigators. In line with this, SIP2 had 14 sub-projects covering three key activities:

- Developing new irrigation technologies, including new sensors, advanced analytics to improve irrigation scheduling, and strategies to reduce water storage evaporation.
- Cost-effective, practical automated irrigation systems for cotton, rice, sugarcane, and dairy.
- A network of 36 farmer-led optimised irrigation sites located on commercial farms across Australia.

The SIP2 Program commenced in July 2019 and will conclude in August 2022.

SIP2 Monitoring and Evaluation

CRDC engaged Ag Econ to undertake an economic analysis of the SIP1 and SIP2 RD&E. This task included:

- 14 Economic case studies for cotton, sugarcane, rice, and grains published on the SIP2 website www.smarterirrigation.com.au
- An Economic analysis report (this document).

An additional five case studies were delivered by D-ARM Consulting for SIP2 dairy research.

The above documents aimed to collate economic data from SIP2 research to inform achievement against the SIP2 economic outcomes, with a specific focus on the targeted 15% increase in productivity from precision automation application in cotton, rice, and sugarcane. In addition, the case studies and economic report sought to provide objective insight into the potential impact of the SIP2 research that could be clearly communicated to industry stakeholders. Figure 1 is a schematic showing the SIP2 overall objectives and targets, with Ag Econ (orange highlight) seeking to assess the project performance for water productivity against a key indicator outlined below.

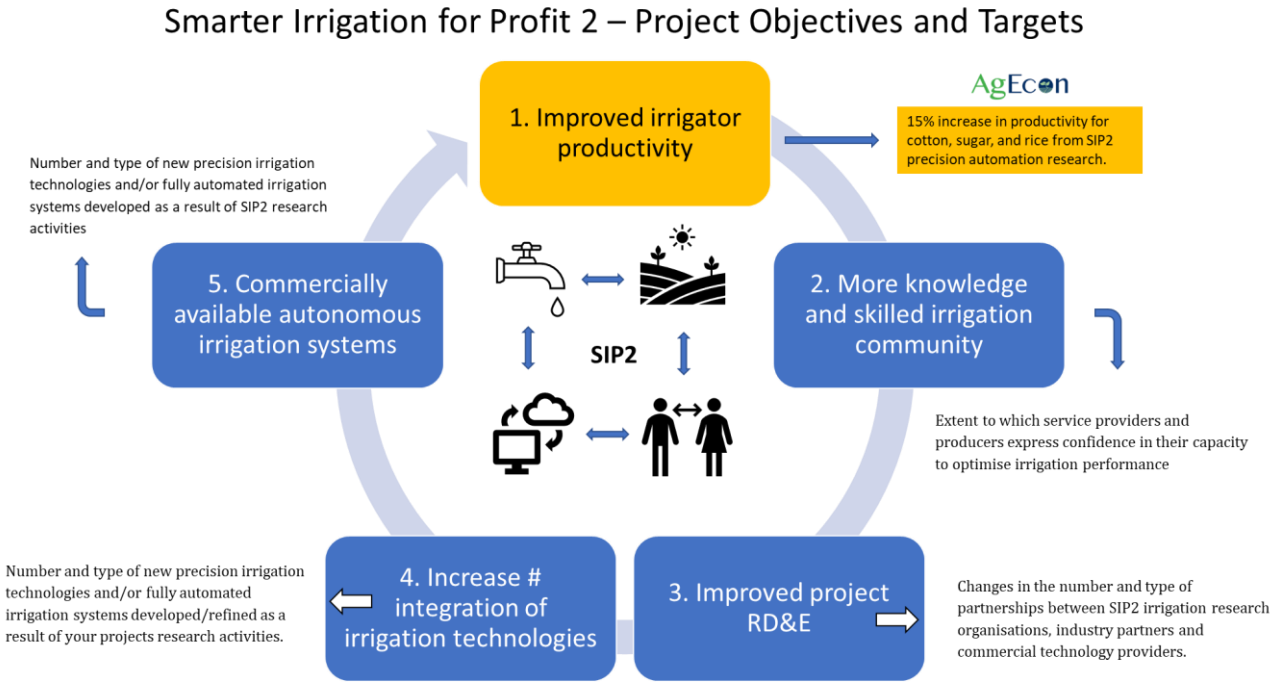

Figure 1. SIP2 overall project objectives and targets, with this report investigating improved productivity as shown in orange highlight.

4. Evaluation Method

Productivity metrics

Productivity refers to the value or volume of output (yield) for a given level of inputs (land, labour, capital, materials, and services). Improving productivity requires an increased level of output for a given level of inputs, or a decreased level of inputs for a given production level.

Productivity is critical to growers because it defines how efficiently a farm uses its resources and how competitively and sustainably (economically, socially, and environmentally) the business is operating. Productivity is similarly significant at an aggregate industry level, given competition for inputs (such as water and labour) from both an economic and socio-environmental perspective (e.g. stewardship).

As elucidated by Batiese (1992), a production function is defined in terms of the maximum output that can be achieved from a specific set of inputs, given the existing technology available to the firms involved. Technical inefficiency occurs if the observed input-output values are below the production frontier, given that firms do not attain the maximum output possible for the inputs involved, given

the technology available (Refer to Figure 7, Appendix 2). Productivity metrics can provide useful insights into best-practice technology, and provide a measure by which the technical efficiency of different firms may be compared.

This study distinguishes between the production technology and environmental factors that impact production outcomes. To be specific, technology under productivity investigation is defined as "a technique, method or system for transforming inputs into outputs" (O'Donnell, 2015). On the other hand, environmental factors consist of all exogenous variables that are physically involved in the production process but that are beyond the control of the firm.

The following metrics have been employed to assess a 15% increase in productivity for cotton, rice and sugarcane as a result of precision automation of irrigation.

Water productivity

Water productivity can be measured through a Water Use Index (WUI). A WUI relates production (yield, return, or gross margin (GM)) to water use (ML) either at the applied (field) or farm level. The various approaches are listed in this section.

1. Irrigation Water Use Index (IWUI): Measuring the product yield per ML of applied irrigation water. IWUI is a valuable measure and is commonly used, particularly for internal farm analysis, as it only accounts for irrigation water and can therefore reflect differences in irrigation management. However, it is less useful for comparison, particularly between different farms or regions, as it takes no account of differences in rainfall (which can significantly influence the amount of irrigation required).

$$IWUI_F = Y/ML_I$$

Where:

Y is crop yield calculated at a per hectare basis

ML_I is megalitres of farm-level irrigation water used (including storage, conveyance, and field losses) calculated at a per hectare basis

2. Gross Production Water Use Index (GPWUI): Measuring the product yield per ML of total available water, including applied irrigation water, effective rainfall, and soil moisture. The use of total water input helps to account for spatial and temporal differences (in rainfall, for example) that lead to different irrigation requirements. As a result, GPWUI is a water productivity (P_w) metric that allows comparison of irrigation performance of different fields or farms across regions and seasons.

$$GPWUI\ (P_W) = Y/ML_T$$

Where:

ML_T is megalitres of total farm-level water used, including ML_I as well as soil moisture used, and effective rainfall calculated at a per hectare basis

Irrigation labour productivity

Analysis of agricultural labour productivity is often measured in terms of the net value added by the equivalent of each full-time worker (Dorward, 2013). However, for field-specific irrigation technology and associated productivity changes, a more appropriate method is output per hour of irrigation labour.

$$Labour\ productivity\ (P_L) = Y/H$$

Where:

H is hours of irrigation labour calculated at a per hectare basis

Irrigation energy productivity

Irrigation energy in this analysis consists of energy used for pumping water from a source, applying it to irrigation fields, and returning runoff. It can also include vehicle energy used in traveling to and from irrigation tasks. Energy productivity can be measured as output per unit of irrigation energy input, and energy input in this analysis is measured as litres (L) of diesel fuel or kilowatt-hours (kWh) of electricity.

$$\textit{Energy productivity } (P_E) = Y/E$$

Where:

E is litres (L) of diesel fuel or kilowatt-hours (kWh) of electricity calculated at a per hectare basis

Capital productivity

Gains in productivity for individual inputs (labour, water, energy) are often achieved through the adoption of innovative technologies, which results in an increased capital base and therefore reduced capital productivity, with the expectation that the net effect will be an improvement in the combined (multi-factor) productivity. As such, a measurement of capital productivity is necessary to assess multi-factor productivity. Capital productivity relating to irrigation has been measured using the output per irrigation capital base. Changes in the irrigation capital base were measured using the Annual Equivalent Cost (EAC) capital budgeting method. This method converts capital investments with different timeframes into a comparable annual figure, thereby allowing a comparison with yearly changes in labour, water, and energy.

$$\textit{Capital productivity } (P_C) = Y / EAC$$

Where:

$$EAC = \textit{Per hectare asset cost} \times \textit{Discount Rate} / (1-(1+\textit{Discount Rate})^{-n}$$

where:

Discount Rate = Opportunity cost of capital

n=effective life of the investment

Multi-factor productivity

Single factor productivity metrics were combined to capture the net irrigation productivity change relating to SIP2 research. Given different unit values of underlying inputs (yield, litres, kWh, megalitres, hours, capital), these were converted to market values for comparison. The final productivity metric compared income (e.g. cotton revenue per hectare) to the total value of inputs (per hectare cost of labour, energy, water, and capital). The water value incorporated the opportunity cost as the next most profitable use of water resources (e.g. additional irrigation cotton production, winter irrigation crop production, or the sale of excess water on the temporary transfer market).

$$\textit{Multi-factor irrigation productivity } (P_I) = Y_V / \sum F_{V\,(W+L+E+C)}$$

Where:

Y_V *= The market value of crop yield or associated output*

$\sum F_V$ *= The sum of irrigation input factors (water, labour, energy, capital) at market prices, or in the case of capital, using the EAC.*

Sustainable productivity: emissions intensity

Through the implementation of irrigation technologies, a reduction in energy or fertiliser use while maintaining crop yields can also form the basis for improvements in sustainable productivity relating

to emissions intensity (Lankoski and Thiem, 2020). Changes in these key cropping inputs can be standardised into carbon dioxide equivalents (CO_2e) per unit output, known as 'emissions intensity' (Powell et al., 2017, Mielenz et al., 2016, Powell et al., 2019). Among the major advantages of the methodology applied here is that it focuses on emission fluxes over which the farmer has direct control, since they happen within the farm-gate. At the global level, these farm- gate emissions are very relevant, as they represent the largest component of agri-food emissions from 1990 to 2019 (FAO, 2020). Therefore, evaluating changes in carbon footprint alongside standard productivity metrics allows smarter irrigation technologies to be evaluated from a broader socio-economic perspective. An emissions intensity numerical equation is derived as follows:

Emissions Intensity change (EI) = emissions reduction per activity / unit of output

Report structure

This economic analysis report brings together and summarises the findings of each case study. Furthermore, it provides a more thorough discussion and additional analysis of the implications for farm-level productivity in the 10-20% target context. It will constitute a final report of the economic research undertaken.

This economic report is structured into three sections:

- The first section summarises the economic case studies for each industry
- The second section undertakes additional single factor and multi-factor productivity analysis with respect to the SIP2 15% productivity target.
- The third section provides a summary and discussion of the findings.

5. Summary of case study findings

This section summarises each of the 19 economic case studies undertaken as part of the SIP2 M&E.

The case studies modelled farm-level impacts of the adoption of SIP2 outputs. For each research area, an appropriate economic framework—such as discounted cash flows (DCF), gross margin (GM) analysis, or partial budget—was selected to provide a simple snapshot of the impact of practice changes, particularly regarding implications for farm productivity and profitability. The farm-level impacts were presented against appropriate single factor productivity metrics as outlined above, as well as investment criteria such as the net present value (NPV), internal rate of return (IRR), and payback period (PBP).

The case studies and associated research are grouped into irrigation management areas, including system selection, monitoring and scheduling, automation and optimisation, water budgeting and gross margins (*Table 1*). Of note, options within management areas are generally mutually exclusive (a system can be set up as either surface irrigation or overhead, not both). In contrast, options across management areas can be cumulative (a given system can be set up with monitoring and scheduling technology, automation, and optimisation).

For each of the case studies and management areas, the report discusses the farm-level impacts regarding water, labour, and energy inputs, as well as any yield impacts. The case study findings are built on later in the report with the additional discussion of capital productivity and multi-factor irrigation productivity.

Cotton

SIP2 cotton research focused on technological and capital investment to improve farm productivity, ranging from major on-farm capital works to seasonal use of field sensors. New South Wales Department of Primary Industries (NSW DPI) benchmarking surveys highlighted the range of WUE in cotton production, with whole-farm irrigation efficiency (WFIE) averaging 59% for the industry,

compared to 70% for the top 25% of growers. This data was used to demonstrate the potential benefits of measuring and benchmarking on-farm WUE, including storage losses, conveyance losses, and field losses, to identify areas for WUE improvements and thereby increase productivity, reduce production risk and increase profitability. As the primary source of farm water losses, on-farm storage evaporation showed strong potential for improving farm WUE. University of Melbourne (UMelb) research highlighted the potential for storage evaporation management (SEM) to reduce farm water losses by 19–35% using chemical monolayers and wind-barriers. Improved monitoring and scheduling through CSIRO's canopy temperature stress (CTS) technology showed productivity gains from increased yield and reduced water usage, as did the University of Southern Queensland's (USQ) automated variable rate application using VARIwise in centre pivot (CP) systems. Deakin Universities research into automation in bankless channel was assessed to provide benefits of reduced labour (–85%) with the potential for additional water savings. The water savings for automated bankless were separately assessed using the HowLeaky water modelling tool, which found a 40% reduction in water when moving from irrigating to saturation compared to irrigating to field capacity. While this highlighted a comparison of extremes, a more likely water saving of 10–20% was also identified. USQ's automated small pipe through bank (sPTB) was also shown to support decreased irrigation labour (–85%) compared to syphon irrigation, with the potential for additional water savings.

Sugarcane

Building skills and capacity of existing research was the primary aim of USQ researchers in irrigated sugarcane. SIP2 economic case studies featured analysis on system selection, automation and optimisation by examining differences in crop gross margins under a range of scenarios. Changing from Big Gun to furrow irrigation found a marked reduction in energy use on one hand (265 kWh/ML), offset by a decrease in labour productivity on the other from managing a low-pressure furrow irrigation system. Automated furrow irrigation found a genuine intersection of both water, energy and labour productivity in sugarcane. This case study revealed up to 25% water savings, improved energy productivity (from reduced water) and lower emissions intensity per tonne of sugarcane. The third analysis involved water budgeting and the timely application of additional irrigations and subsequent additional yield benefit. Results showed high marginal returns from additional water in the Mackay region. However, the magnitude of these benefits was dependent on yield response functions, with benefits varying from 3-15% cane yield increase per ML.

Grains

The aim of the SIP2 grains research partners included the utilisation of irrigation water to improve the profit of irrigators using new technologies and more informed decisions for optimal applications of water. Crop Gross Margin analysis was the preferred method employed to determine the highest profit per hectare and per ML for cereal crops at Kerang, central Victoria. Results found pre-irrigating in autumn provided the greatest yield response and highest per ML returns. Historical climate data showed rainfall to be less reliable during planting, therefore irrigating during this period improved yield potential prior to spring season when rainfall was more reliable. Central West Farming Systems (CWFS) at Condobolin, NSW conducted detailed variety trials and irrigation scenario analysis to establish an economic decision framework to improve farmer profit. The first scenario examined purchasing water in drought conditions when cereal crops were either cut for hay or grain. Break-even gross margin analysis showed high per ML and per hectare returns when crops were cut for hay, even during periods of historically high temporary water prices. The final economic case study focused on alternative land use via dual purpose winter crops for grazing and grain production. The study found high gross margins per hectare and per ML through the addition of livestock as a dual source of income. When crops were irrigated and grazed early, per ML returns exceeded break-even market values for water, resulting in improved profits. Outcomes were sensitive to the value of water assumption used.

Rice

Researchers at Deakin University conducted trials of smart sensing and automation in southern NSW irrigated rice production. The objectives of the study were to increase profit using smart automation systems using a range of sensors to measure soil and water parameters that robotically control irrigation events. The findings revealed the greatest productivity gains were made from labour savings, where the input of this resource was reduced by 85%. However, while water saving data was not available at the time this was later estimated at more than 10%, which has the potential to more than double the benefits depending on the value of water.

Dairy

SIP2 research in dairy focussed on irrigation scheduling, variable rate irrigation, and system improvements. The Tasmanian Institute of Agriculture (TIA) set up soil moisture monitoring equipment on a focus farm in northern Tasmania to research implement improved irrigation scheduling practices on a centre pivot. The research found an additional 3.6 t DM/ha/year could be generated with better-quality scheduling, which was enough to offset an additional 1.25 ML/ha/year of applied water, as well as increased labour costs. In a border check system, Agriculture Victoria trials showed that irrigation management could be further optimised with the use of water sensors in conjunction with satellite technology, which reduced irrigation durations, saving 0.9 ML/ha/year in water use, and with associated reductions in pumping costs. System upgrades were investigated by NSW DPI, with the research identifying potential improvements in distribution uniformity and irrigation efficiency with the incorporation of a larger mainline and a new sprinkler pack in a centre pivot system. These system upgrades were assessed to generate an additional 1 t DM/ha/year, a reduction of $1,000 /year in energy costs, and a reduction of $1,000/year in repairs and maintenance costs. Finally, research into variable rate irrigation in centre pivot by TIA in Tasmania found that a range of benefits were generated depending on the site, including additional yield of 1.8 t DM/ha/year, a reduction of 1.9 ML/ha/year water, and reduction of $105 /ha/year in energy costs. Separate trials in Western Australia found higher yield gains of 3 to 4 t/DM/ha/year. Overall, the dairy case studies highlighted a range of irrigation productivity improvements readily available to the industry.

Table 1: Summary of SIP2 economic case studies. Case studies can be found at www.smarterirrigation.com.au .

Industry	Water Management Area	Study Title	Productivity outcomes
Cotton	Monitoring and scheduling	Canopy temperature stress monitoring	3% cotton yield increase 1 in 2 years Save 1 irrigation every 3 years
	Automation and optimisation	Siphon to small pipe through the bank	85% reduction in irrigation labour
		Smart sensing and automation in bankless channel	85% reduction in irrigation labour
		Improved water productivity through automated bankless irrigation	>20% water savings
		Automated variable rate irrigation in CPLM with VARIwise	3.6% cotton yield increase 10.6% reduction in water use
	Water budgeting and gross margins	Evaporation mitigation solutions	19-35% reduction in storage evaporation losses
		Economics of measuring WUE	16% reduction in water use (moving from average to top 25% industry)
Sugarcane	System selection	Big gun to furrow	265 kWh / ML energy savings Decreased labour productivity
	Automation and optimisation	Water and Energy benefits of automation	25% water saving 338 kWh/ha energy saving 273 CO_2e /ha/yr emissions abatement
	Water budgeting and gross margins	Marginal benefit of water	3-14% cane yield increase from additional 1 ML/Ha
Grains	Water budgeting and gross margins	When to irrigate: Seasonal returns per ML	Optimal irrigation timeliness: Pre-irrigate Barley, Canola & Beans Irrigation at wheat flowering optimal
		Hay water decision matrix: sell, buy, or apply?	Cutting cereal crops for hay can lead to the highest $/ML returns in drought years
		Economics of dual-purpose winter crops shows stellar returns	Grazing early sown crops achieved the highest $/ML returns compared with grain only crops
Rice	Automation and optimisation	Smart irrigation control in bankless channel	85% reduction in irrigation labour
Dairy	Monitoring and scheduling	Improved irrigation scheduling to increase pasture growth in northern Tas.	Additional 3.6 t DM/ha/year Additional 1.25 ML/ha/year water Additional 0.16 hr/ha/year labour use
		Satellite technology to save irrigation water in northern Vic.	Reduction of 0.9 ML/ha/year water use Reduction of $210/ha/year pumping costs
	System selection	New mainline and a sprinkler pack for a centre pivot in southern NSW to improve pasture growth and save energy	Additional 1 t DM/ha/year Reduction of $1,000/year in power costs Reduction of $1,000/year in repairs and maintenance costs
	Automation and optimisation	Variable Rate Irrigation and improved scheduling to increase pasture growth and save energy and water — Tas.	Additional 1.8 t DM/ha/year Reduction of 1.9 ML/ha/year water Reduction of $105/ha/year in power costs
		Variable Rate Irrigation and improved scheduling to increase pasture growth and save energy and water — WA.	Additional ~3 – 4 t DM/ha/year

6. Productivity analysis

This section applies the single-factor and multi-factor productivity metrics to the SIP2 research areas to evaluate the productivity implications of the SIP2 research. Due to data limitations, the productivity analysis focusses on cotton, sugarcane, grains and rice.

Data

Costs and benefits of SIP2 research were drawn from SIP2 research findings. Where data gaps existed, the SIP2 data was augmented by SIP1 research results, and other industry data and assumptions where appropriate. A full list of data and sources is in Appendix 1.

The findings of this report should be viewed in the context of the small data sets and necessary use of assumptions. Further, the productivity findings relate to the specific system, season, management, and climate dynamics of the underlying farms. In particular, the approach does not account for climate effects, particularly in the presence of long-term climate change. As authors Chancellor et al. (2021), (Njuki et al., 2018) discussed, Australian agricultural total factor productivity is extremely sensitive to both short-run and long-term climate change. The key argument is that irrigated agriculture will be impacted primarily due to changing configurations of temperature and precipitation, leading to modifications in farming patterns and resource use. Novel approaches to accounting for water productivity and climate effects include crop yield per evapotranspiration of the cropping system required to bring the crop to maturity (Comas et al., 2019). These provide a basis for future water productivity research.

Cotton

Irrigation productivity was calculated for nine irrigation systems, including baseline systems and systems augmented with SIP2 research outputs. For consistency, and due to limited baseline data from SIP2 research trials, baseline data was drawn from the Keytah System Comparison (GVIA, 2022). Figure 1 shows the multi-factor irrigation productivity across each system and technology combination for cotton production.

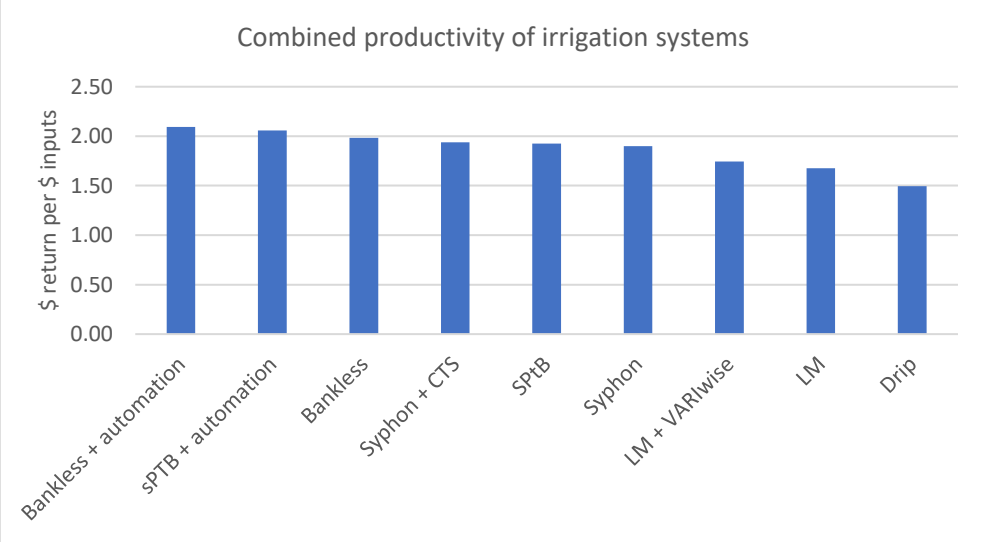

Figure 1. Multi-factor irrigation productivity for evaluated cotton systems and SIP2 research areas.

Table 2 breaks this down into the different single-factor and multi-factor productivity metrics for each system and technology combination. Each column, showing the productivity metrics, is shaded to show how different levels of irrigation productivity align to the each systems and technologies.

Table 2. Partial factor and total irrigation productivity for baseline cotton systems, and SIP2 cotton research. SIP2 research areas are in italics.

System	Farm level WUE		Labour productivity	Energy productivity	Capital productivity	Combined productivity
	IWUI	GPWUI				
Bankless + automation	1.73	1.14	185.46	0.07	0.021	2.09
sPTB + automation	1.56	1.06	121.89	0.06	0.027	2.06
Bankless	1.56	1.06	27.82	0.06	0.022	1.98
Syphon + CTS	1.50	1.01	3.76	0.05	0.035	1.94
sPTB	1.41	0.99	18.28	0.05	0.029	1.93
Syphon	1.41	0.99	3.53	0.05	0.037	1.90
LM + VARIwise	2.00	1.18	21.34	0.04	0.011	1.74
LM	1.75	1.08	20.84	0.03	0.012	1.67
Drip	1.64	1.04	49.25	0.02	0.010	1.49
Syphon + SEM	1.58	1.07	3.53	0.06	NA	NA

While this highlights the most productive systems and technologies against key inputs, it does not demonstrate the marginal benefits of each system and technology.

To highlight marginal gains in productivity more clearly, *Table 3* shows the percent improvement in productivity. Each system is compared to furrow irrigation as a baseline. Each technology is compared to the same system without the technology.

Table 3. Change in partial factor and total irrigation productivity for cotton case study systems and SIP2 cotton research. SIP2 research is shown in italics.

Baseline comparison	Farm level WUE		Labour productivity	Energy productivity	Capital productivity	Combined productivity
	IWUI	GPWUI				
Syphon to drip	16%	6%	1294%	-55%	-73%	-21%
Syphon to lateral move	24%	9%	490%	-35%	-67%	-12%
Syphon to sPTB	0%	0%	418%	0%	-22%	1%
Apply CTS to syphon	*7%*	*2%*	*7%*	*7%*	*-2%*	*2%*
Syphon to bankless	11%	7%	687%	17%	-40%	4%
Apply VARIwise to LM	*15%*	*10%*	*2%*	*15%*	*-4%*	*6%*
Apply automation to bankless	*11%*	*7%*	*567%*	*11%*	*-3%*	*6%*
Apply automation to sPTB	*11%*	*8%*	*567%*	*11%*	*-3%*	*7%*
Apply SEM in syphon	*12%*	*8%*	*0%*	*11%*	*NA*	*NA*

Table 3 shows that changes in total productivity ranged from a decrease of 21% when comparing a drip system to a baseline syphon system, to an increase of 7% when comparing automated sPTB to sPTB.

It should be noted that differences in system productivity are based on site-specific data in northern NSW. So while the data provides a good comparison for that particular farm, the results would certainly have been different for a farm with a different climate and soil types. As such, lower productivity identified in this analysis (for example drip and lateral move) should not preclude consideration of irrigation systems for different cotton farms.

The productivity gains differed across the SIP2 research areas, with single-factor productivity gains averaging 82% across the water, labour, and energy (with a median of 8% reflecting the large outliers in labour productivity gains). All of these inputs showed potential single-factor productivity gains of the target 15% for at least one SIP2 research area.

For each system modification or technology application, the reduced labour, capital, water, and energy inputs, or increased yield, were achieved through an increase in capital inputs. For all SIP2 research, the increased capital base outweighed any increased production (yield), thereby decreasing capital productivity by an average 6% (median 6%).

For all SIP2 research, the productivity gains from labour, water, and energy outweighed the decreased capital productivity, generating average multi-factor irrigation productivity gains of 5% (median 5%).

Focusing on the individual SIP2 research areas, automation systems provided relatively high increases in labour productivity. In contrast, variable rate irrigation through VARIwise and storage evaporation management provided relatively high water and associated energy savings. CTS and VARIwise were the only SIP2 research areas that included a yield change (increase).

While labour showed the highest average unit productivity gains, for most system and technology changes, water savings contributed more to multi-factor irrigation productivity due to the relatively high value of water inputs compared to irrigation labour. The exception to this was for system changes from syphon to bankless channel and syphon to sPTB, for which productivity changes were both driven by labour productivity gains.

As capital costs for some of the SIP2 research areas (such as automation in bankless and sPTB) are largely dependent on gate numbers, the per hectare cost could be reduced with larger bay sizes, supporting higher capital productivity and multi-factor productivity with these investments.

Sugarcane

Applying more irrigation water

This sugarcane economic analysis measured the marginal costs and benefits of applying more irrigation water to sugarcane. The main purpose of this study was to reveal the substantial gap where benefits exceeded costs early in season when a yield increase followed. Under the assumptions used in the baseline scenario, the cane irrigator was operating at the lower end of the marginal response to irrigation water (below optimum yield), where incremental water inputs typically achieve a larger proportion of yield gains. In this instance the irrigator is operating inside the production frontier (see Appendix 2, Figure 1) at a point of technical inefficiency (Batiese, 1992). The resulting productivity metrics showed a general reduction in efficiency or productivity for the addition or 1 ML / ha (*Figure 2*). Due to diminishing marginal returns on additional water, the increased water application results in decreased productivity for all scenarios, despite a positive yield response. However, this does not infer that it is uneconomical to apply additional water, as the additional yield (marginal revenue) can still generate higher value than the additional (marginal) cost of irrigation water. Changes in energy productivity was negligible in all scenarios.

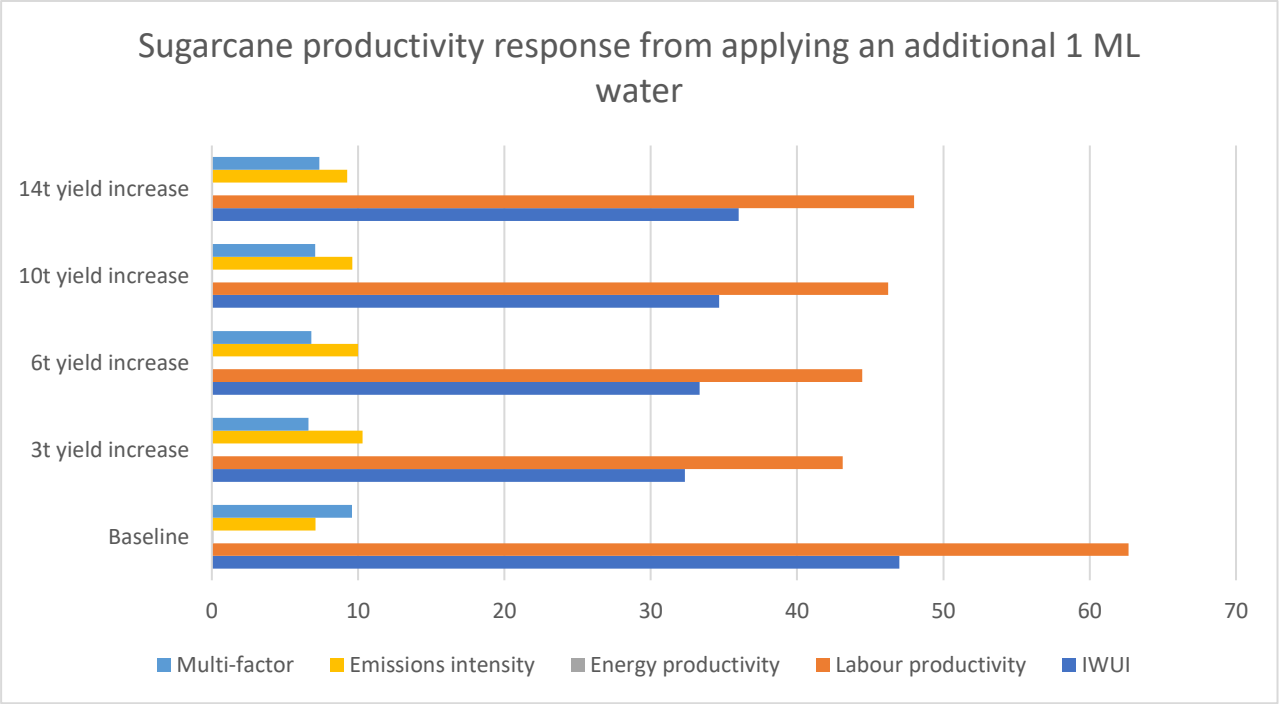

Figure 2 Sugarcane productivity measures from an additional 1 ML/ha water applied from baseline conditions

Big Gun to furrow and adopting automation

Two economic analyses in irrigated sugarcane uncovered vastly different productivity responses. A change from energy intensive big gun water application to furrow irrigation found water use and energy productivity gains, at the cost of decreased labour productivity. Emissions intensity was also greatly reduced, showing a lower carbon footprint per yield output. The multi-factor productivity also showed a favourable 30% increase from this practice change. Analysis of furrow automation in the Burdekin region showed that through implementing automation, water savings and subsequent reduced energy use found improved IWUI and reduced emissions, as well as increased multi-factor productivity of 165% particularly due to labour savings. The productivity changes for both sugarcane research areas are illustrated in *Figure 3*.

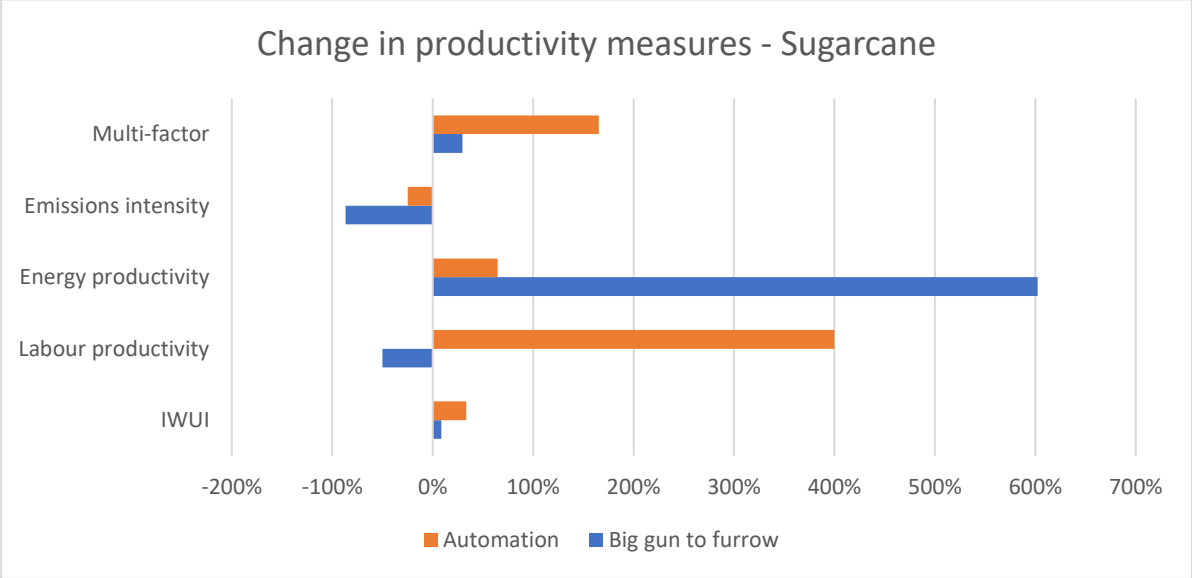

Figure 3 Changes in productivity measures under irrigation practice changes in sugarcane: big gun vs furrow irrigation, Bundaberg region, Qld; and automation of furrow irrigation, Burdekin region, QLD.

Grains

Optimising irrigation timing

The aim of this collaborative research was to improve the capability of growers and extension staff to use irrigation information, partial gross margins and tools and make cost-effective irrigation decisions. This analysis investigated timeliness of irrigation on several winter crops to improve WUE and optimise water productivity at Kerang, Victoria. *Figure 4* shows the results when comparing optimal irrigation vs business as usual scenarios. Pre-irrigating canola crops showed large gains in productivity and vast improvements in water productivity compared to no pre-irrigation. Similarly, a spring irrigation of wheat was more optimal than a fully irrigated crop in the year of the experiment. When moving from fully irrigated to partially irrigated wheat, the marked reductions in capital productivity (due to reduced yield) were offset by water savings; however, this was dependent on the value of the water savings (i.e. return per ML for the next best use of water), with a breakeven water value of $140/ML identified in the scenario. Emissions intensity was lowered, or improved (i.e. lower CO2e per output) in both canola and wheat scenarios.

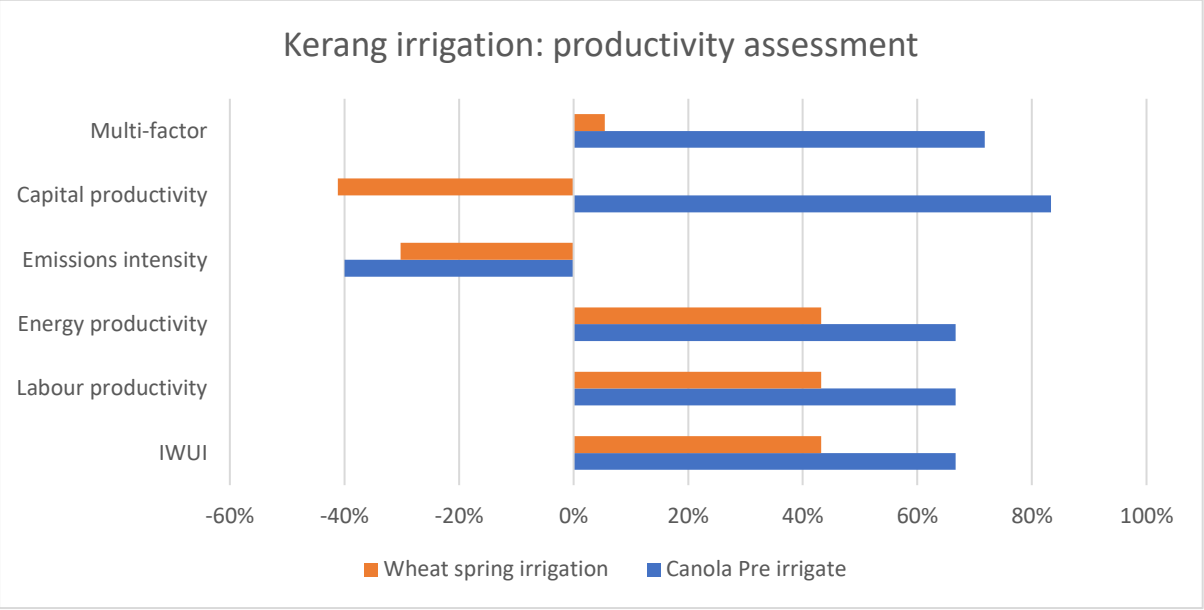

Figure 4 Measured changes in productivity of irrigated canola (no pre irrigation vs pre irrigation) and fully irrigated wheat vs a single spring irrigation at Kerang, Victoria.

Optimising irrigated crop type and land use

In a recent project undertaken by CWFS, the economics of irrigation and wheat varieties were assessed for grain and hay yield. The aim of these trails was to help growers make cost-effective irrigation decisions through on-farm demonstration. A number of variety trails were conducted over the two-year period. Applying a partial gross margin approach, cutting cereal hay results far exceeded grain only recovery in terms of $/ha and $/ML returns. Trials on dual purpose cereal and canola crops seeking to find the most optimum use of water uncovered standout productivity gains when grazing canola was irrigated early. Similarly, irrigated wheat grazed early and destocked prior to grain harvest found impressive multi-factor productivity gains. These results are shown in *Figure 5*.

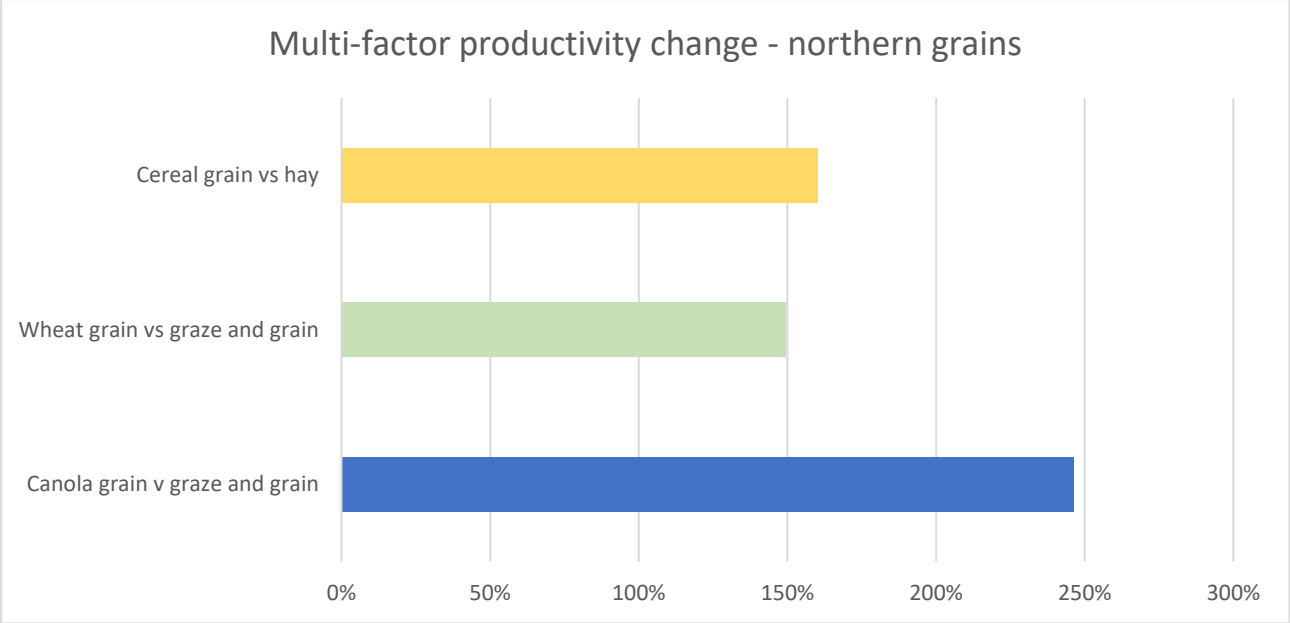

Figure 5 changes in multi-factor productivity from various variety, land use and irrigation trial conducted in the northern grains region by CWFS.

Rice

For SIP2 rice research, productivity changes were evaluated for one research area: automation in bankless channel systems. The changes were compared to baseline system productivity for bankless channel. *Table 4* shows the multi-factor irrigation productivity for the baseline system and with the addition of automation.

Table 4. Partial factor and multi-factor irrigation productivity for baseline rice system, and SIP2 rice research.

System	Farm level WUE		Labour productivity	Energy productivity	Capital productivity	Combined productivity
	IWUI	GPWUI				
Bankless channel	0.89	0.77	5.39	1.23	0.02	1.13
Apply automation to bankless	0.98	0.85	35.94	1.37	0.02	1.24

To highlight marginal gains in productivity more clearly, *Table 5* shows the percent improvement in productivity moving from bankless to bankless with automation.

Table 5. Change in partial-factor and multi-factor irrigation productivity from SIP2 rice research.

System	Farm level WUE		Labour productivity	Energy productivity	Capital productivity	Combined productivity
	IWUI	GPWUI				
Apply automation to bankless	11%	10%	567%	11%	-5%	9%

Table 5 shows that the muti-factor irrigation productivity increased by 9% with the application of smart automation. While unit labour productivity showed the greatest increase, improved water productivity contributed the most to the change in multi-factor productivity due to the relative higher value of water inputs compared to labour. As capital costs are largely dependent on gate numbers, the upfront cost per hectare reduces with larger bay sizes, supporting higher capital productivity and multi-factor productivity.

7. Discussion and conclusions

Productivity summary

Figure 6 shows the average water and multi-factor productivity gains across the analysed industries. Water productivity (IWUI) changes ranged from an average 5% increase (sugarcane) to an average 133% increase (grains). Multi-factor productivity changes ranged from an average 5% increase (cotton) to an average 127% increase (grains). Across all industries, SIP2 research generated average water productivity improvements of 40% (with industry averages ranging from 5% to 133%, median 11%) and an average multi-factor productivity gain of 50% (ranging from 5% to 127%, median 35%).

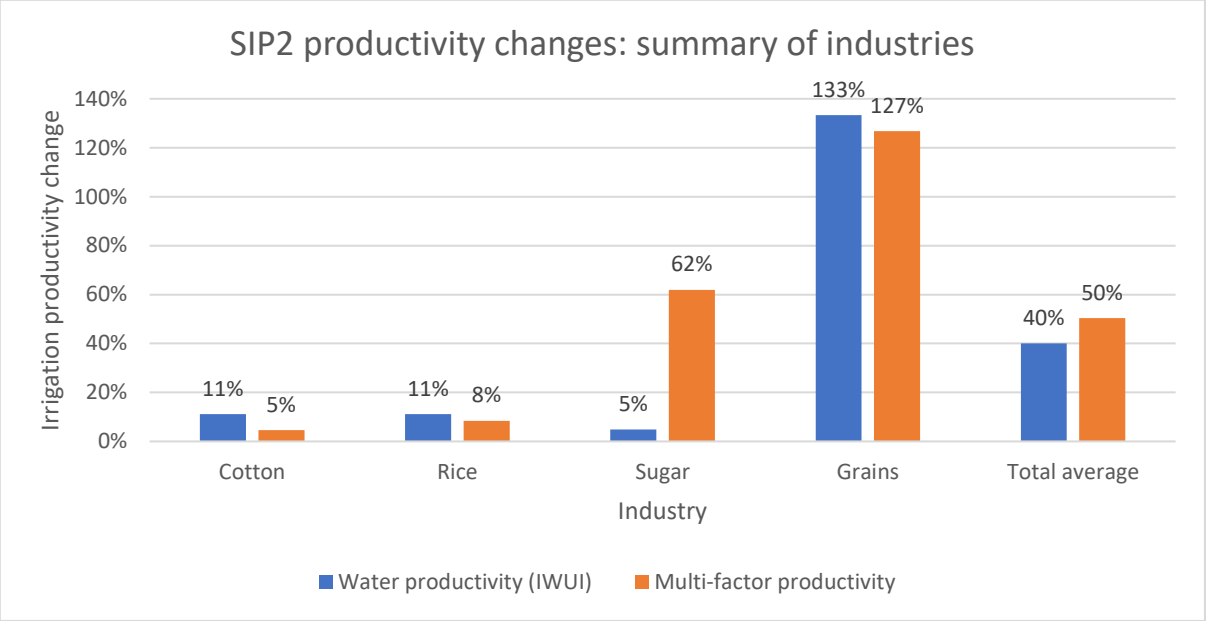

Figure 6: Summary of water (IWUI) and multifactor productivity measures assessed across cotton, rice, sugarcane and grains industries including the combined total

Discussion

The productivity changes across SIP2 projects and industries included an interesting mix of results and underlying drivers.

Figure 6 highlights significant difference in productivity changes between industries; with grains particularly standing out. This was due to a stronger focus on capital intensive technology application in cotton and rice systems, where gains in yield or reduced water, labour, and energy inputs, were generated through increased capital investment, thereby resulting in a smaller combined multi-factor productivity. In comparison, grains achieved increased yield through a strategic timing of water application, or multi-purpose cropping (cropping plus grazing, and grain plus hay), neither of which required an offsetting investment in capital.

In regards to the specific SIP2 target of 15% productivity gains from precision automation in cotton, rice and sugarcane (i.e. excluding research not related to precision automation), the analysis found an average water productivity increase of 18% (range 11% to 33%, median 11%) and an average multi-factor productivity increase of 59% (range 5% to 165%, median 8%). Looking specifically at each industry, the analysis of four precision automation technologies in cotton (canopy temperature sensing, variable rate application, and automation in both bankless and small pipe through the bank) found an average water productivity gain of 12% (range 11% to 15%, median 11%) and an average multi-factor productivity gain of 6% (range 4% to 7%, median 6%). For rice, automation in bankless channel was found to achieve a water productivity gain of 11% and an average multi-factor

productivity gain of 8%. Automation of furrow irrigation in sugarcane was found to achieve a water productivity gain of 33% and an average multi-factor productivity gain of 165%.

The large variation in results reflects the differences in underlying industries inputs and outputs, the technologies being applied, and also the data availability. Not all optimisation and learning sites collected all the relevant productivity data, so estimates were made based on researcher or grower estimates. As such, the findings of this report should be viewed in the context of the small data sets and necessary use of assumptions. In some cases, a lack of data impeded an economic evaluation for participating sectors. Future research objectives and outcomes should be supported by the collection of relevant data across all underlying research activities, including the baseline data collection. Such data collection should be specifically included in research outputs and budgeted at the start, as once contracts are signed leverage is almost impossible, especially with large multi-party applications.

Labour inputs experienced some of the largest unit changes in precision automation; however, when valued at market prices, the value of water savings typically outweighed the value of labour savings. However, due to data limitations, this did not account for variability and risk. Due to a greater confluence of exogenous factors (climate, season, irrigation system, and other farming practices), there is often a higher level of uncertainty regarding the level of water savings (ML/ha) and also the value of saved water ($/ML that can be generated from saved water). Of note, however, the cotton and rice automation analysis highlighted that even without water savings, labour savings alone were sufficient to generate positive returns on investment.

The analysis of applying additional irrigation water to sugarcane or grains highlighted the implications of diminishing returns on water inputs. Yield gains get smaller and smaller with every additional ML of applied water, resulting in decreasing productivity. This, however, does not mean that it is uneconomical to apply the additional water, as the economic optimum can be found where the marginal cost (value of additional water) is equal to the marginal benefit (value of additional yield). As such, the most economic rate of water application will not be equal to the highest water productivity (yield or revenue per ML) and will also not necessarily be equal to the highest yield. The extent to which the most economic rate of water differs will depend on the relative prices of the water inputs ($/ML) and enterprise outputs ($/unit of yield), which in turn are impacted by climate and market forces. This also underscores the need for irrigators to have the ability to respond appropriately and in a timely fashion to relative changes in commodity prices and farm input prices which are expected to be increasingly likely because of climate change.

The cotton analysis showed that due to the higher upfront capital outlay, system changes (for example syphon to bankless channel, or syphon to sPTB) resulted in lower productivity gains compared to automation (automation on bankless and automation on sPTB). However, not captured in the productivity metric is that these system changes also provide the ability for further management upgrades in the form of automation or optimization that are not as easily applied to syphon irrigation. As such, these system upgrades are necessary steps to achieve the higher productivity gains through automation.

In line with the above point, the analysis looked at each SIP2 research topic in isolation, whereas some of the outputs are cumulative. As an example, moving from syphon to automated bankless channel increases productivity by a total of 10% (compared to approximately 4% for the system change alone, and 6% for automation). This example could be extended further to also incorporate SEM and improved scheduling (CTS); however, due to differences in the underlying trials we do not have the data to demonstrate this.

Climate change has significant consequences for the irrigation and energy sectors. The irrigation sector in particular faces major challenges in a water and energy-constrained future. The SIP2 research has shown there is significant potential in irrigated agriculture for water savings through the adoption of water use efficient irrigation technologies and management practices. These have proven outcomes of achieving increased water productivity as well as increased water availability for

either expanding irrigation areas or alternative uses. However, interventions at the farm level which result in increased energy consumption and GHG emissions may result in significant trade-offs between climate change adaptation and mitigation strategies. In this regard, a more informative irrigation productivity metric would include emissions intensity to capture any potential trade-off between single-factor productivity changes. In addition, the potential trade-off between single-factor productivity elements illustrates a critical point, that climate adaptation approaches such as conversion to new water-efficient irrigation technologies must be evaluated in the context of wider climate change mitigation strategies to optimize both economic and socio-environmental outcomes. Those practices that showed alignment between improved water use efficiency and emissions intensity (from lower energy use) include applying automation sensors and crop modelling across cotton, sugarcane, and rice sectors, moving to furrow irrigation from big gun application in sugarcane, and increasing farm output with less water through multi-purpose cropping of irrigated grains. These results indicate that positive synergies can be achieved at the farm level, creating a win-win situation where irrigation technology adoption not only saves water but also reduces energy use and GHG emissions.

The productivity calculations have also not accounted for longer term climate effects but provided a static appraisal. As emphasised by Chancellor et al. (2021), estimates of total factor productivity can be highly sensitive to climate variability and obscure short-term productivity trends.

Conclusions and recommendations

The primary objective of this report was to evaluate the SIP2 program against the target of 15% productivity gains from precision automation in cotton, rice and sugarcane. Considering this sub-set of SIP2 research, the analysis found an average water productivity increase of 18% (range 11% to 33%, median 11%) and an average multi-factor productivity increase of 59% (range 5% to 165%, median 8%). Based on these results, the productivity target is considered achieved, with variation around the target depending on the industry, technology, farm dynamics, and market conditions.

The results looked at productivity gains for individual investments but highlighted the potential for larger productivity gains from a combination of research recommendations and outputs. The results reflect the small data sets and generic assumptions needed to fill data gaps, and do not account for the socio-economic costs and benefits of emissions, or the long-term impacts of climate change.

Key recommendations from the analysis are that:

- Funders should consider requiring data collection for economic analysis as a mandatory component of all funding applications. This will help to ensure a robust evaluation against stated research objectives, and an assessment of the research value proposition to support extension. This would also be supported by the development of an economic framework as part of project or program planning to inform data collection.
- The emissions intensity of agricultural industries adopting technology should be carefully monitored to avoid inadvertent environmental outcomes that indirectly impact agricultural sustainability. Productivity data collection frameworks should consider these broader sustainability implications by capturing any potential trade-off between single-factor productivity changes relating to climate change mitigation (reducing greenhouse gas emissions) and adaptation (reducing water use). Incorporating emissions intensity into the data collection and productivity framework would support this broader analysis.

8. References

BATIESE, G. E. 1992. Frontier production functions and technical efficiency: a survey of empirical applications in agricultural economics. *Agricultural Economics,* 7**,** 185-208.

CHANCELLOR, W., HUGHES, N., ZHAO, S., SOH, W. Y., VALLE, H. & BOULT, C. 2021. Controlling for the effects of climate on total factor productivity: A case study of Australian farms. *Food Policy,* 102**,** 102091.

COMAS, L. H., TROUT, T. J., DEJONGE, K. C., ZHANG, H. & GLEASON, S. M. 2019. Water productivity under strategic growth stage-based deficit irrigation in maize. *Agricultural Water Management,* 212**,** 433-440.

DORWARD, A. 2013. Agricultural labour productivity, food prices and sustainable development impacts and indicators. *Food Policy,* 39**,** 40-50.

FAO 2020. *The share of agriculture in total greenhouse gas emission. Global, regional and country trends 1990–2017.,* Rome, Italy.

LANKOSKI, J. & THIEM, A. 2020. Linkages between agricultural policies, productivity and environmental sustainability. *Ecological Economics,* 178**,** 106809.

MIELENZ, H., THORBURN, P. J., HARRIS, R. H., OFFICER, S. J., LI, G., SCHWENKE, G. D. & GRACE, P. R. 2016. Nitrous oxide emissions from grain production systems across a wide range of environmental conditions in eastern Australia. *Soil Research,* 54**,** 659-674.

NJUKI, E., BRAVO-URETA, B. & O'DONNELL, C. 2018. A new look at the decomposition of agricultural productivity growth incorporating weather effects. *PLOS ONE,* 13**,** e0192432.

O'DONNELL, C. 2015. Using information about technologies, markets and firm behaviour to decompose a proper productivity index. *Journal of Econometrics,* 190.

POWELL, J. W., WELSH, J. M. & ECKARD, R. J. 2017. An irrigated cotton farm emissions case study in NSW, Australia. *Agricultural Systems***,** 61.

POWELL, J. W., WELSH, J. M., PANNELL, D. & KINGWELL, R. 2019. Can applying renewable energy for Australian irrigated sugarcane reduce energy cost and environmental impacts? A case study approach. *Journal of Cleaner Production,* Under Review.

9. Appendix 1. Productivity data.

Cotton

Variable	Value	Unit	Source
Baseline yield			
Syphon	12.51	b/ha	GVIA 2009-2021 5y av.
LM	12.64	b/ha	GVIA 2009-2021 5y av.
Bankless	12.80	b/ha	GVIA 2009-2021 5y av.
Drip	12.15	b/ha	GVIA 2009-2021 5y av.
Yield change			
CTS (on existing furrow)	1.5	% baseline	Goanna Ag
VARIwise (on existing LM)	2.4	% baseline	USQ
SEM (with existing furrow)	0.0	% baseline	U Melb
Automation (on existing bankless)	0.0	% baseline	Deakin University & Padman Automation
sPTB (on existing furrow)	0.0	% baseline	Assumption
Automation (on existing sPTB)	0.0	% baseline	Assumption
Net revenue / bale	506.9	$/bale	Ag Econ multi merchant 10y av. CPI adjusted to 2022. Less yield based costs (CottonInfo GM)
Baseline applied water			
Syphon	6.41	ML/ha	GVIA 2009-2021 5y av.
LM	5.21	ML/ha	GVIA 2009-2021 5y av.
Bankless	5.92	ML/ha	GVIA 2009-2021 5y av.
Drip	5.35	ML/ha	GVIA 2009-2021 5y av.
Applied water change			
CTS (on existing furrow)	-4.8	% baseline	Goanna Ag
VARIwise (on existing LM)	-10.6	% baseline	USQ
SEM (with existing furrow)	0.0	% baseline	U Melb
Automation (on existing bankless)	-10.0	% baseline	Bankless channel case study (Welsh, 2022)
sPTB (on existing furrow)	0.0	% baseline	Assumption
Automation (on existing sPTB)	-10.0	% baseline	Bankless channel case study (Welsh, 2022)
Water cost	204	$/ML	BOM waterdashboard 10y av. CPI adjusted to 2022, plus $8.6/ML av usage charges, plus 2 x $8/ML pump maintenance.
In crop rainfall	4.43	ML/ha	GVIA 2009-2021
Effective rainfall			
Syphon	79	% of rainfall	GVIA 2009-2021 5y av.
LM	81	% of rainfall	GVIA 2009-2021 5y av.
Bankless	79	% of rainfall	GVIA 2009-2021 5y av.
Drip	81	% of rainfall	GVIA 2009-2021 5y av.
Used soil moisture			
Syphon	0.29	ML/ha	GVIA 2009-2021 5y av.
LM	0.93	ML/ha	GVIA 2009-2021 5y av.
Bankless	0.37	ML/ha	GVIA 2009-2021 5y av.
Drip	0.59	ML/ha	GVIA 2009-2021 5y av.

Conduit efficiency			
Storage losses	25	%	NSW DPI 2017-18
Channel losses	3	%	NSW DPI 2017-18
Storage losses change with SAM	-35	%	U Melb
Labour use			
Syphon	3.54	h/ha/yr	GVIA 2009-2021 5y av. Plus 0.18h/ha/yr travel
LM	0.61	h/ha/yr	GVIA 2009-2021 5y av. Plus 0.05h/ha/yr travel
Bankless	0.46	h/ha/yr	GVIA 2009-2021 5y av. Plus 0.18h/ha/yr travel
Drip	0.25	h/ha/yr	GVIA 2009-2021 5y av. Plus 0.05h/ha/yr travel
Labour use change			
CTS (on existing furrow)	-4.8	% baseline	Goanna Ag
VARIwise (on existing LM)	0.0	% baseline	USQ
SEM (with existing furrow)	0.0	% baseline	U Melb
Automation (on existing bankless)	-85.0	% baseline	Roth G et al. (2018), and Deakin University
sPTB (on existing furrow)	-80.7	% baseline	Assumption 85% saving of syphon change labour based off Roth G et al. (2018). Travel time unchanged
Automation (on existing sPTB)	-85.0	% baseline	Assumption based off Roth G et al. (2018)
Labour cost	50.0	$/h	Assumption
Pumping diesel use			
Surface water to storage double lift.	25.3	L/ML	Ag Econ 2021-22 GM.
Storage to field and tailwater for:			
Syphon	2.8	L/ML	GVIA 2018
Bankless channel	0.7	L/ML	GVIA 2018
LM	38	L/ML	Ag Econ 2021-22 GM.
Drip	63	L/ML	Ag Econ 2021-22 GM.
Diesel cost	0.98	$/L	AIP, 10y av. CPI adjusted to 2022, less GST and $0.442/L rebate
Capital cost (upfront)			
Syphon	1,054	$/ha	GVIA 2018, CPI adjusted to 2022.
LM	4,090	$/ha	GVIA 2018, CPI adjusted to 2022.
Bankless	2,108	$/ha	GVIA 2018, CPI adjusted to 2022.
Drip	8,960	$/ha	GVIA 2018, CPI adjusted to 2022.
CTS (on existing furrow)	0	$/ha	Goanna Ag.
VARIwise (on existing LM)	1,189	$/ha	A. McCarthy, USQ. Moveable with rotation.
SEM (with existing furrow)	NA	$/ha	Not available
Automation (on existing bankless)	312	$/ha	Deakin University & Padman Automation. Moveable with rotation.
sPTB (on existing furrow)	539	$/ha	J. Foley, USQ.
Automation (on existing sPTB)	152	$/ha	J. Foley, USQ. Moveable with rotation.
Capital cost (maintenance)			
Syphon	109	$/ha/yr	GVIA 2018, CPI adjusted to 2022.

LM	175	$/ha/yr	GVIA 2018, CPI adjusted to 2022.
Bankless	170	$/ha/yr	GVIA 2018, CPI adjusted to 2022.
Drip	71	$/ha/yr	GVIA 2018, CPI adjusted to 2022.
CTS (on existing furrow)	25	$/ha/yr	Goanna Ag
VARIwise (on existing LM)	16	$/ha/yr	USQ
SEM (with existing furrow)	NA	$/ha/yr	U Melb
Automation (on existing bankless)	$7	$/ha/yr	Deakin University & Padman Automation
sPTB (on existing furrow)	$8	$/ha/yr	USQ
Automation (on existing sPTB)	$6	$/ha/yr	USQ
Useful life			
Syphon	50	years	GVIA 2018
LM	20	years	GVIA 2018
Bankless	50	years	GVIA 2018
Drip	40	years	GVIA 2018
CTS (on existing furrow)	1	years	Goanna Ag
VARIwise (on existing LM)	15	years	USQ
SEM (with existing furrow)	NA	years	U Melb
Automation (on existing bankless)	10	years	Deakin University & Padman Automation
sPTB (on existing furrow)	25	years	USQ
Automation (on existing sPTB)	10	years	USQ
Cost of capital	5	%	Assumption

Rice

Variable	Value	Unit	Source
Baseline yield			
Bankless	10.8	t/ha	ABS 7121 average 2017-18 to 2019-20
Yield change			
Automation (on existing bankless)	0.0	% baseline	Deakin University & Padman Automation
Net revenue / tonne	346.5	$/tonne	ABARES Rural Commodities – Rice (2021) 10y av. CPI adjusted to 2022. Less yield based costs (Rice$cenario GM)
Baseline applied water			
Bankless	12.2	ML / ha	ABS 4618 average 2017-18 to 2019-20
Applied water change			
Automation (on existing bankless)	-10.0	% baseline	Deakin University
Water cost	188	$/ML	BOM waterdashboard 10y av. CPI adjusted to 2022, plus $8.6/ML av usage charges.
In crop rainfall	2.25	ML/ha	BOM Griffith average Oct-Apr
Effective rainfall	79	% of rainfall	Assumption. (GVIA 2009-2021 5y av. Cotton bankless channel.)
Used soil moisture	0	ML/ha	Assumption

Conduit efficienct	100	% farm water	Assume minimal losses due to direct supply from MIA system to field.
Labour use			
Bankless	2.0	h/ha/yr	Deakin University. 8 ha bay.
Labour use change			
Automation (on existing bankless)	-85.0	% baseline	Roth G et al. (2018), and Deakin University
Pumping diesel use			
Tailwater pumping	0.7	L/ML	Assumption. (GVIA 2018. Cotton bankless channel.)
Diesel cost	0.98	$/L	AIP, 10y av. CPI adjusted to 2022, less GST and $0.442/L rebate
Capital cost (upfront)			
Bankless	2,187	$/ha	Assumption. (GVIA 2018. Cotton bankless channel. CPI adjusted to 2022.)
Automation (on existing bankless)	373	$/ha	Deakin University & Padman Automation. Moveable with rotation.
Capital cost (maintenance)			
Bankless	170	$/ha/yr	Assumption. (GVIA 2018. Cotton bankless channel. CPI adjusted to 2022.)
Automation (on existing bankless)	10	$/ha/yr	Deakin University & Padman Automation
Useful life			
Bankless	50	years	Assumption. (GVIA 2018. Cotton bankless channel.)
Automation (on existing bankless)	10	years	Deakin University & Padman Automation
Cost of capital	5	%	Assumption

Sugarcane

Variable	Value	Unit	Source
Baseline yield			
Mackay (big gun)	94	t/ha	Feat online Gross Margin
Bundaberg (big gun)	80	t/ha	Feat online Gross Margin
Burdekin (furrow)	124	t/ha	Feat online Gross Margin
Yield response			
Mackay (big gun)	3,6,10 & 14	t/ha	Michael Scobie
Net revenue / tonne	38.19	$/tonne	Feat online Gross Margin
Baseline applied water			
Mackay (big gun)	2	ML/ha	Feat online Gross Margin
Bundaberg (big gun)	8	ML/ha	Feat online Gross Margin
Burdekin (furrow)	20	ML/ha	Feat online Gross Margin
Applied water change			
Mackay (big gun)	-1	ML/ha	SIP2 Case Study – Marginal benefit of irrigation
Bundaberg (big gun to furrow)	-0.64	ML/ha	SIP2 Case Study – Big Gun to Furrow
Burdekin (furrow automation)	-5	ML/ha	SIP2 Case Study – Furrow automation
Water cost	50	$/ML	Feat online Gross Margin

Baseline labour use			
Mackay (big gun)	1.5	h/ha	SIP2 Case Study – Marginal benefit of irrigation
Bundaberg (big gun)	1.5	h/ha	SIP2 Case Study – Big Gun to Furrow
Burdekin (furrow)	7.1	h/ha	SIP2 Case Study – Furrow automation
Labour use change			
Mackay (big gun)	+0.75	h/ha	SIP2 Case Study – Marginal benefit of irrigation
Bundaberg (big gun to furrow)	+1.5	h/ha	SIP2 Case Study – Big Gun to Furrow
Burdekin (furrow automation)	-5.7	h/ha	SIP2 Case Study – Furrow automation
Labour cost	35	$/h	Assumption
Baseline energy use			
Mackay (big gun)	822	kWh	SIP2 Case Study – Marginal benefit of irrigation
Bundaberg (big gun)	309	kWh	SIP2 Case Study – Big Gun to Furrow
Burdekin (furrow)	8220	kWh	SIP2 Case Study – Furrow automation
Energy use change			
Mackay (big gun)	+411	kWh	SIP2 Case Study – Marginal benefit of irrigation
Bundaberg (big gun to furrow)	-265	kWh	SIP2 Case Study – Big Gun to Furrow
Burdekin (furrow automation)	-2055	kWh	SIP2 Case Study – Furrow automation
Energy cost	0.27	c/kWh	Assumption
Capital cost (upfront)			
Automation	700	$/ha	SIP1 Malcolm Gillies report
Big Gun	5700	$/ha	SIP2 Case Study – Big Gun to Furrow
Furrow	5250	$/ha	SIP2 Case Study – Big Gun to Furrow
Capital cost (maintenance)			
Big Gun	150	$/ha/yr	Assumption. (GVIA 2018. Cotton centre pivot. CPI adjusted to 2022.)
Furrow	110	$/ha/yr	Assumption. (GVIA 2018. Cotton syphon irrigation. CPI adjusted to 2022.)
Automation (on existing bankless)	7	$/ha/yr	Deakin University & Padman Automation
Useful life			
Big gun	25	years	Assumption.
Furrow	50	Years	Assumption. (GVIA 2018. Cotton syphon irrigation.)
Automation (on existing furrow)	10	years	Deakin University & Padman Automation
Cost of capital	5	%	Assumption

Grains

Variable	Value	Unit	Source
Revenue			
Kerang canola (no-pre irrigation)	1080	$/ha	SIP2 Case Study – When to irrigate
Kerang canola (pre-irrigation)	1980	$/ha	SIP2 Case Study – When to irrigate

Kerang wheat (full irrigation)	3690	$/ha	SIP2 Case Study – When to irrigate
Kerang wheat (1 x irrigation)	2172	$/ha	SIP2 Case Study – When to irrigate
CWFS wheat	1200	$/ha	SIP2 Case Study – Irrigation water in dry years
CWFS hay	3124	$/ha	SIP2 Case Study – Irrigation water in dry years
CWFS canola grain	506	$/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS canola grain/graze	1753	$/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS wheat grain	298	$/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS wheat grain/graze	744	$/ha	SIP2 Case Study — Irrigated dual-purpose crops
Applied water			
Kerang canola (no-pre irrigation)	2.5	ML/ha	SIP2 Case Study – When to irrigate
Kerang canola (pre-irrigation)	2.75	ML/ha	SIP2 Case Study – When to irrigate
Kerang wheat (full irrigation)	3.65	ML/ha	SIP2 Case Study – When to irrigate
Kerang wheat (1 x irrigation)	1.5	ML/ha	SIP2 Case Study – When to irrigate
CWFS wheat	3	ML/ha	SIP2 Case Study – Irrigation water in dry years
CWFS hay	3	ML/ha	SIP2 Case Study – Irrigation water in dry years
CWFS canola grain	1.5	ML/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS canola grain/graze	1.5	ML/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS wheat grain	1.5	ML/ha	SIP2 Case Study — Irrigated dual-purpose crops
CWFS wheat grain/graze	1.5	ML/ha	SIP2 Case Study — Irrigated dual-purpose crops
Water cost			
Kerang	204	$/ML	BOM waterdashboard 10y MDB av. CPI adjusted to 2022, plus $8.6/ML av usage charges.
CWFS wheat/hay	311	$/ML	SIP2 Case Study – Irrigation water in dry years
CWFS grain/graze	485	$/ML	SIP2 Case Study — Irrigated dual-purpose crops
Labour use			
Kerang canola (no-pre irrigation)	1.88	h/ha	SIP2 Case Study – When to irrigate
Kerang canola (pre-irrigation)	2.06	h/ha	SIP2 Case Study – When to irrigate
Kerang wheat (full irrigation)	2.74	h/ha	SIP2 Case Study – When to irrigate
Kerang wheat (1 x irrigation)	1.13	h/ha	SIP2 Case Study – When to irrigate
CWFS wheat/hay	2.25	h/ha	SIP2 Case Study – Irrigation water in dry years
CWFS grain/graze	1.13	h/ha	SIP2 Case Study — Irrigated dual-purpose crops
Labour value	35	$/h	Assumption
Energy use			
Kerang canola (no-pre irrigation)	341		SIP2 Case Study – When to irrigate
Kerang canola (pre-irrigation)	375		SIP2 Case Study – When to irrigate
Kerang wheat (full irrigation)	495		SIP2 Case Study – When to irrigate

Kerang wheat (1 x irrigation)	205		SIP2 Case Study – When to irrigate
CWFS wheat/hay	410		SIP2 Case Study – Irrigation water in dry years
CWFS grain/graze	278		SIP2 Case Study — Irrigated dual-purpose crops
Energy cost	0.27	c/kWh	Assumption
Capital cost (upfront)			
Syphon	1,054	$/ha	Assumption. (GVIA 2018. Cotton syphon irrigation.)
Capital cost (maintenance)			
Syphon	109	$/ha/yr	Assumption. (GVIA 2018. Cotton syphon irrigation.)
Useful life			
Syphon	50	Years	Assumption. (GVIA 2018. Cotton syphon irrigation.)
Cost of capital	5	%	Assumption

10. Appendix 2 Production frontier

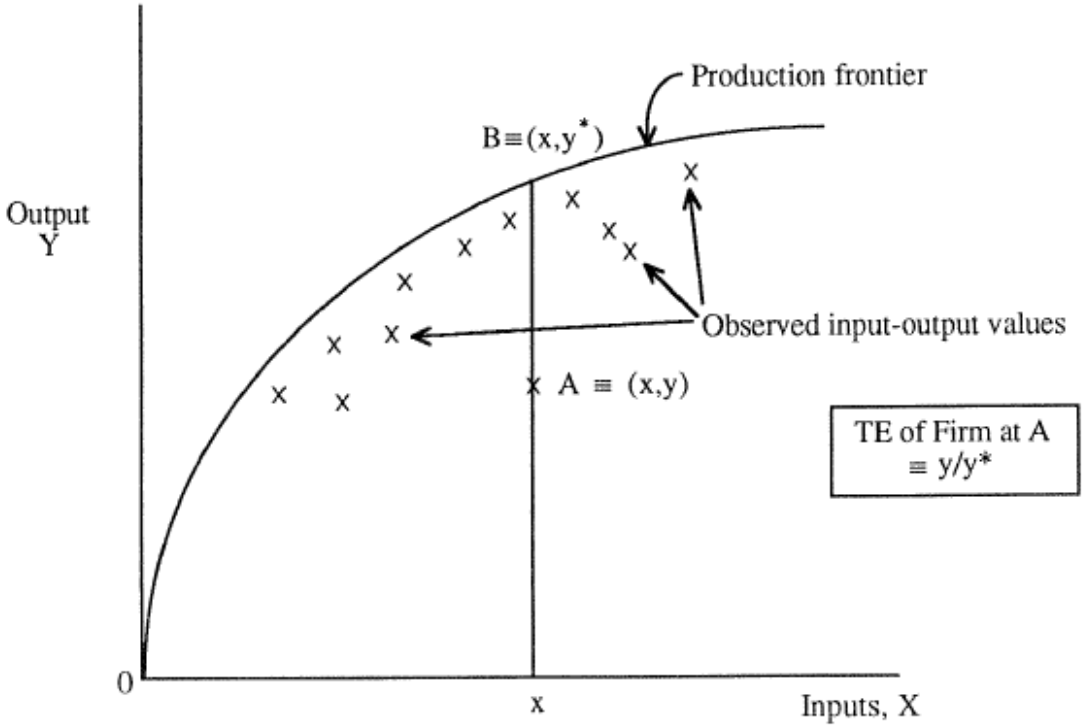

Figure 7 the Technical Efficiency of firms input-output space, depicted by a production frontier (Batiese, 1992)