Department of Primary Industries
and Regional Development

Final Report

CRDC DAN 2303: Water productivity benchmarking in the Australian cotton industry

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COTTON RESEARCH AND DEVELOPMENT CORPORATION

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Executive summary

Purpose and Scope

The project aimed to benchmark water productivity in irrigated and rainfed cotton systems across Australia to support sustainable water use and improve farm profitability. It builds on previous benchmarking initiatives and introduces annual reporting for both systems.

Key Objectives

- Annual benchmarking and reporting of water productivity in irrigated and rainfed cotton in the context of sustainable water use
- Updating long-term trends of water productivity for irrigated cotton
- Establishing benchmarks for rainfed cotton and refining rainfed cotton water productivity model

Major Findings

Irrigated Cotton:

- The CRDC DAN2303 project confirms that the Australian cotton industry has achieved world-leading water productivity and sustainability outcomes
- GPWUI improved from 0.62 bales/ML (1997) to 1.13 bales/ML (2024), 25-year average of 1.07 bales/ML
- In 2024, The top 20% farms achieved ≥1.26 bales/M and SWUI averaged 1.01 ML/bale (4,460 L/kg), less than half global requirement and
- Despite this progress, seasonal variability — driven by droughts, floods, and climate extremes — remains a major challenge, causing fluctuations in water productivity.
- However, the resilience and recovery observed in recent seasons demonstrate the adaptability of Australian cotton systems under favourable conditions

Rainfed Cotton:

- Rainfed cotton benchmarking, introduced for the first time under this project, shows promising potential for expansion
- The average yields rose from 3.07 in 2023 to 4.08 bales/ha in 2024
- The average CWUI improved from 1.01 to 1.13 bales/ML
- Performance variability across farms and regions highlights the need for targeted research into soil moisture, rainfall distribution, and stress factors

Implications

Benchmarking remains an essential tool for guiding improvements, supporting sustainability reporting, and strengthening the industry's social license and market access. Australia leads globally in cotton water productivity, aligning with UN SDGs (6, 12, 13). Continued investment in precision irrigation, climate adaptation, and farmer training is essential.

Rainfed cotton offers potential for expansion but needs targeted research on soil, rainfall timing, and management strategies.

Conclusion

The CRDC DAN2303 project confirms that the Australian cotton industry has achieved world-leading water productivity and sustainability outcomes. Over the past 28 years, irrigated cotton has more than doubled its water-use efficiency, with GPWUI rising from 0.62 bales/ML in 1997 to 1.13 bales/ML in 2024, and SWUI averaging 1.01 ML/bale, less than half the global requirement.

Rainfed cotton benchmarking shows promising potential for expansion, but variability highlights the need for targeted research. Continued investment in precision irrigation, climate adaptation strategies, and farmer training will be critical to maintaining leadership and addressing future challenges.

Recommendations

- Expand data collection to cover a wider range of regions and seasons for both irrigated and rainfed cotton farms.
- Assess the management practices used by farms performing in the top 20% for GPWUI to identify key drivers of high water productivity.
- Develop targeted strategies to improve water productivity for farms currently performing below the average GPWUI, as well as for average-performing farms aiming to progress into the top 20%.
- Integrate soil-moisture monitoring technologies and further refine water-productivity models for rainfed cotton systems.
- Investigate the influence of rainfall timing and explore management interventions that address non-water-related yield constraints in rainfed cotton

Introduction

Benchmarking water productivity in irrigated cotton

Global competition for freshwater is intensifying due to rising demands for food, fibre, biofuels, and environmental needs. Enhancing agricultural water productivity by producing more yield per unit of water, is essential to ease pressure on limited water resources (Mekonnen and Hoekstra 2014).

The Australian cotton industry contributes AUD $2–$3 billion annually to the national economy and is a major global supplier. Around 80% of cotton is irrigated, grown on deep alluvial soils from Central Queensland to Southern NSW, with expansion into northern Australia and increasing rainfed production. To remain viable and sustainable, the industry must boost water productivity, particularly by increasing lint yield per megalitre (ML) of water used.

Australian cotton growers face increasingly limited and unreliable access to water. Additionally, water use is highly scrutinised by domestic and international consumers and supply chains. The cotton industry has been proactive in managing water consumption by providing ongoing support for monitoring, benchmarking and reporting cotton water productivity.

Tennakoon and Milroy (2003) established a baseline for water use efficiency in the 1990s, using the Gross Production Water Use Index (GPWUI), expressed as bales/ML. Successive Water Productivity Benchmarking Projects led by NSW DPI include CRDC 5.01.13 and CRDC DAN 005162 (NPSI) from 2006/07 and 2008/09 cotton seasons, respectively, demonstrated a 40% improvement in water use efficiency between the 1990s and 2000s. The projects CRDC DAN1205 and DAN1505, in 2012/13 and 2017/18, respectively, demonstrated a 97% improvement over 20 years.

Data collection in these historical projects was intensive, expensive and time consuming for growers and researchers, resulted in the benchmarking activity was only conducted at irregular intervals of up to nine years. This left significant data gaps between sampling years, which can act as 'blind-spot' for the industry, risking lost opportunity for improvement and causing 'holes' in the story of long-term water use trends.

To address this, the subsequent Benchmarking project, Trends & Drivers DAN2002, collated and analysed historic water use data from past cotton industry research (Cameron & Hearn 1997; Dalton et al. 2001; Wigginton 2001; QRWUE 2003) to fill some gaps. DAN2002 also facilitated data sharing agreements with industry partners (CSD Ambassador program & CRDC grower survey, myBMP program and consultants) to enable annual updates of cotton water productivity moving forward.

Water productivity can be calculated in many ways, depending on the components of the water balance that are included, and the scale at which they are measure. For this reason, comparison of water productivity between projects or farms or years, can be confusing if it is not clear what is being measured and compared.

The NSW DPI Benchmarking Projects established the standard use of GPWUI (Gross Productive Water Use Index) as the standard for water use efficiency. GPWUI includes all water consumed at the farm level for growing cotton. This includes all licenced water brought onto farm, all water held in storage and all evaporative losses, all water intercepted as rainfall runoff and overland flow, and all effective rainfall on fields and all soil moisture. GPWUI also accounts for water losses from evaporation, seepage, and irrigation inefficiencies. While GPWUI is the most complete and preferred metric for water use efficiency, the data required to calculate this metric is not always recorded. CRDC DAN2002 and the current project (CRDC DAN 2303) collaborated with industry partners to add value to their data collection. For example, both Projects added extra questions in myBMP water modules and CRDC Grower Survey, on water held in storage and soil moisture, to enable calculation of GPWUI from these resources and add value to their dataset.

The average GPWUI serves as a benchmark reported by the industry to track progress, drive improvements, and support practice change (Tennakoon and Milroy 2003; Montgomery and Bray 2010; Williams and Montgomery 2010; Roth et al. 2013; Montgomery et al. 2014; Perović et al. 2019). In the current project (CRDC DAN 2303), the value of GPWUI achieved by the top 20% of the farm sampled is also reported to serve as aspirational goal for individual grower.

Benchmarking water productivity in rainfed cotton

In the past, water productivity has only been reported for irrigated cotton so DAN2002 collaborated with the Sustainability working group to develop indices for measuring water productivity in dryland cotton, and a methodology for estimating industry-wide water productivity, including identifying available data resources. It incorporated several milestones associated with developing water productivity benchmarking of dryland cotton. These include a literature review of methods for measuring water productivity rainfed systems that would be most appropriate for dryland cotton in Australia, forming data sharing partnerships to access dryland cotton data for benchmarking and developing a methodology for benchmarking industry wide water productivity.

An increased focus on rainfed cotton is important because increasing pressure on irrigation water availability makes dryland cotton an increasing attractive option, including potential to expand the industry into higher rainfall areas in northern Australia. Additionally, most of the cotton grown around the world is from dryland production, so it is important for international comparisons.

Rainfed cotton systems has been practiced in Australia since early 1990s to gain maximum yield from limited water (Stiller and Constable 1998). The area of rainfed cotton grown in Australia is smaller than that in other countries. For example, in the late 1990s, about 100–150 thousand ha of Australian cotton was grown as rainfed compared to 2 million ha of rainfed or partially irrigated cotton in Texas, US (Stiller and Constable 1998).

Australian rainfed cotton grown in summer-dominant rainfall regions contributes up to 18% of the annual production of Australian cotton (Figure 1b), depending on the season. The area of rainfed cotton sown fluctuates on a yearly basis between 0.6–47% of total cotton area (Figure 1a) depending on seasonal rainfall and cotton price (CRDC 2002). Consequently, most of the cotton yield is from the irrigated system. The strong causality between yield and water availability (Kanber et al. 1996; Cetin and Bilgel 2002) led to lower yield of rainfed cotton compared to irrigated cotton (Figure 1c).

In rainfed cotton systems, the lack and uncertainty of rainfall, timing and distribution of rainfall events is the biggest constraint to production. The primary objective of management under rainfed system is to maximise the efficiency in capturing, storing and use of rainfall by the crop. The main indicator of this is water productivity, which demonstrates how efficiently the system converts soil water into cotton lint (bales).

The cotton industry is built on water scarcity which necessitates use efficiency. This means to maximise the efficiency of water conversion into lint yield, termed as water productivity (WP) expressed in either lint /ML or kg lint /mm of water used. The economic value (productivity) of water used to produce cotton is expressed in GM$/ML. To indicate the sustainable water use and comparison across system, the unit used megalitre/bale or litre/kg lint (i.e. how much water is consumed for every kg of cotton lint produced on farm).

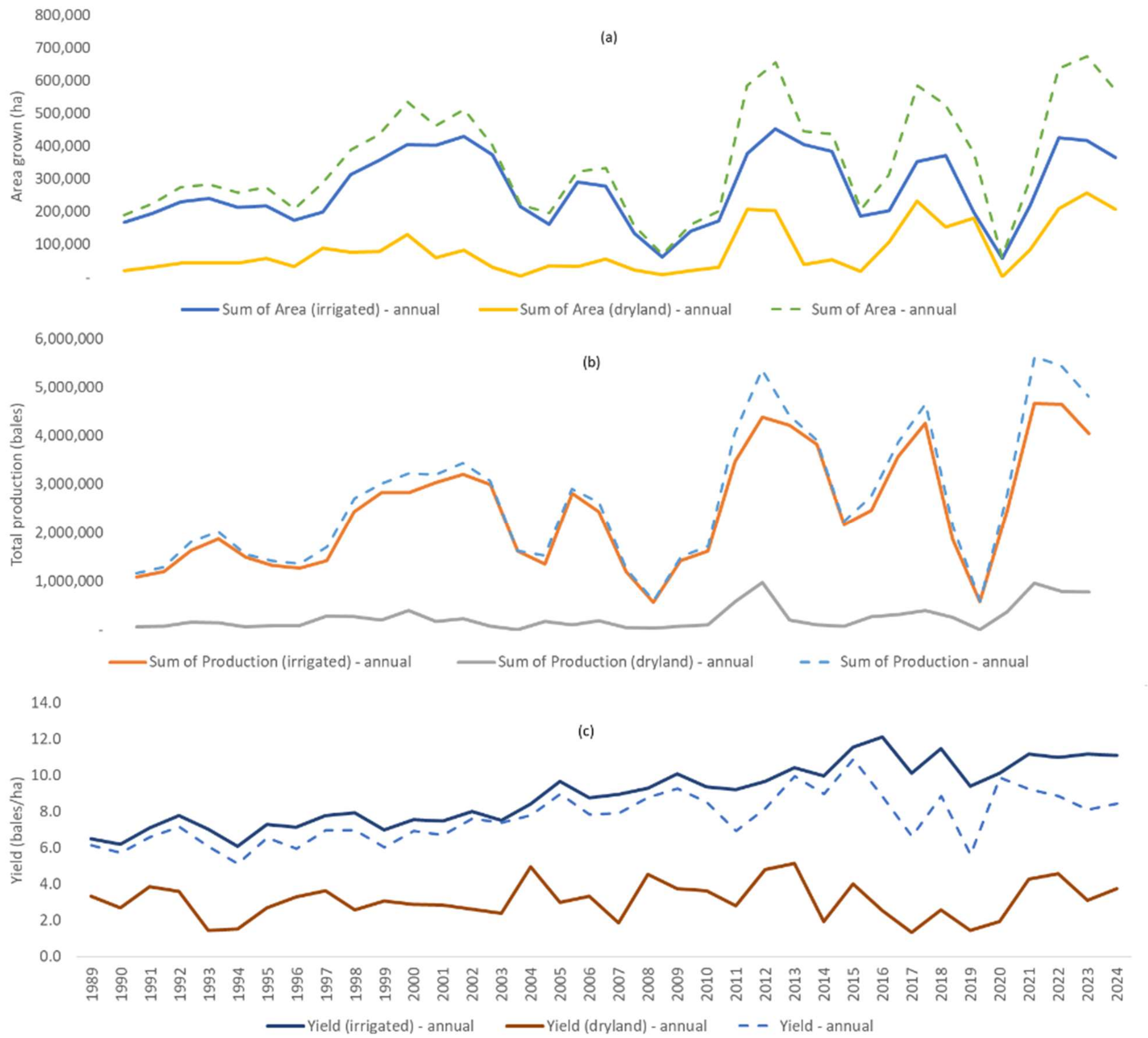

Figure 1. Annual cotton production in Australia (drawn from unpublished data)

While CRDC's benchmarking program since the 1990s has improved the understanding about the trends and drivers of water productivity of irrigated cotton, there has been no coordinated research assessing water productivity for rainfed cotton and subsequently little published data are available on its water productivity.

This Cotton Benchmarking project (CRDC DAN2303), co-funded by CRDC and NSW DPIRD, is he first research that includes the assessment of rainfed cotton water productivity. The initial assessment of rainfed water productivity and sustainability indicators in this project lays a foundational dataset and methodology for the industry to improve and expand in the future, provides basic understanding of rainfed cotton water productivity, as well as identification of research gaps to improve this understanding. Most importantly, the results will enable rainfed cotton growers to benchmark the productivity of their farm in the context of their peers, to set target based on their farm's biophysical conditions and to select management strategies that will help them to achieve this target.

Objectives

The objectives of Project CRDC DAN2303 are to:

1. Annual benchmarking and reporting the water productivity in irrigated cotton in the context of sustainable water use,
2. Update and report the long-term trends of water productivity of irrigated cotton,
3. Validation of rainfed cotton water productivity model, and
4. Annual benchmarking and reporting of water productivity in rainfed cotton in the context of sustainable water use.

Materials and methods

Establishing water productivity benchmarks

Since the 1990s the Australian cotton industry has commissioned researchers from various organisations to benchmark the water productivity of Australian Cotton, and it was conducted at irregular intervals of up to 9 years. Since the 20217/2018 season[1], DPIRD (formerly NSW DPI) has led the benchmarking project and benchmarked cotton water productivity annually until 2024.

Farm and water records are collected from major Australian cotton growing regions. The sample size (farm number) fluctuated annually depending on the grower's availability and willingness to participate and share their farm records with the project. The maximum number of farms sampled were 46 farms sampled (2021 and 2024) and accounting for up to 8.0% of total industry annual production. For the duration of DAN2303 project (2022 – 2024), the sample size ranged from 16 to 46 farms which represent 2.05% to 7.90% of the annual industry production (Table 2Table 2. The number of farms participating in the benchmarking for 2022, 2023 and 2024 harvests years. The total for the year is presented in cells shaded grey, irrigated cotton in light blue and rainfed cotton in light red.). These farms were located within the regions[2] listed in Table 1.

Table 1. Regions sampled for water productivity benchmarking. The region's name is adapted to previous reporting for consistency

Region name	Subset areas included	State
Balonne	St George	QLD
Central Queensland	Dawson, Callide	QLD

[1] Cotton crop in Australia is sown in spring/summer month and harvested in autumn/early winter the following year. Throughout this report cotton season is either identified as the crop season (i.e. 2021/2022 season) or harvest year (i.e. 2022 for crop sown in 2021 and harvested in 2022)

[2] The naming of cotton growing regions or valleys is currently inconsistent between various industry sources and projects, and within the historic benchmarking projects. The industry's efforts to standardise the regions name is currently underway.

Darling Downs		QLD
Gwydir		NSW
Border River/MacIntyre	Dumaresq	NSW/QLD border
Macquarie		NSW
Namoi	Lower Namoi, Upper Namoi	NSW
Southern NSW	Murrumbidgee	NSW
Douglas-Daly		NT

Project DAN2303 updated the trends of long-term water productivity indicator annually between with 1997 selected as the starting point, when a complete dataset was available for the first time. The average water productivity (GPWUI) value has been used as the benchmark since 1990s (Tennakoon and Milroy 2003; Montgomery and Bray 2010; Williams and Montgomery 2010; Roth et al. 2013; Montgomery et al. 2014; Perović et al. 2019) and it is also used in this project. However, this project also presents the water productivity value for the top 20% of farms (80th percentile) to reflect an aspirational goal for individual grower.

The project CRDC DAN2303 also established other key indicators such as sustainable water use index (SWUI) and the economic water use efficiency indicator or gross value of water productivity (GVWP) to reflect the UN Sustainable Development Goals 6.4.

Both SWUI and GVWP are described in detail in the subsequent sections.

Data collection

The estimation of farm water performance indicators relies on farm records provided by individual cotton grower. Each year the project team contacted over 100 cotton growers and consultants across major cotton growing regions. These growers contact were either sourced from previous benchmarking projects, through collaboration with CottonInfo's and CSD Regional Extension Officers (REOs), and through benchmarking teams' attendance in cotton field days and grower meetings. Detailed annual sample size is presented in Table 2.

The target was at to obtain records from at least five farms per valley/region. However seasonal availability dictated actual annual participation. It's important to note that not all growers can be involved annually, the benchmarking is not a longitudinal study.

Prior to data collection, each grower was given a brief background about the benchmarking project, its objectives and benefits to the industry and to individual grower. The brief also specifies the type of farm data required and the consent from grower to use the information they provided for the purpose of the project, and how the privacy of grower/farm will be protected by only using the information they provided for this project only.

Table 2. The number of farms participating in the benchmarking for 2022, 2023 and 2024 harvests years. The total for the year is presented in cells shaded grey, irrigated cotton in light blue and rainfed cotton in light red.

Harvest year		2022*	2023	2024
Total sample Irrigated + Rainfed	Area, ha and (% industry)	8,315* (1.95)	42,731 (6.35)	45,153 (7.91)
	Production, bales and (% industry)	95,573* (2.05)	398,275 (7.32)	380,226 (7.90)
	Valleys			
Irrigated Cotton	Number of farms	16	47 (45)	46 (43)
	Area, ha	8,315	32,067 (29,278)	27. 179 (27,016)

Harvest year		2022*	2023	2024
sampled and (reported)	Production, bales	95,573	365,035 (352,383)	314, 243 (312,973)
Rainfed cotton sampled and (reported)	Number of farms	NA	28 (28)	33 (32)
	Area, ha	NA	10,665 (10,665)	17,971 (16,96)
	Production, bales	NA	33,240 (33,240)	65,983 (62,886)

Farm records obtained from each grower include gin yield, farm water storage, soil water, rainfall (obtained from either the grower or from BOM/SILO database), farm layout and field information such as crop management, irrigation system and soil type (see details in Table 3). The grower records were used to calculate several water performance indicators such as gross production water use index (GPWUI), sustainable water use index (SWUI), crop water use, whole farm irrigation efficiency (WFIE), and various component of water losses. The calculation methods for these indicators are described in the section below.

Similar information is collected from rainfed cotton farms but without irrigation water components and is used to calculate crop water use index (CWUI) and SWUI.

Table 3. Types of farm record collected for water productivity benchmarking

Record type	Details	Purpose
Grower details	Name, contact details (telephone number or email)	Communication
Farm information	Property name, location, map showing field layout within the farm	Estimation of crop Etc, water input and output to storages and channels
Cotton crop	Area (ha) and total yield (bales) including refuge	To calculate water productivity
Soil water and climate record	Moisture probe data and weather record (or their service provider contact details)	Estimation total farm water and crop ETc
Farm water record (ML) and movement for the season	Storage volumes (ML) at: the end of previous season, the start and end of the current season Pre-irrigation water (ML or ML/ha) Irrigation water used for other crops (ML) Channel leaks or operational losses (ML) Source of irrigation water (ML): water courses, irrigation scheme, groundwater bores, rainfall runoff and floodplain harvesting	Water accounting to determine total irrigation water and total farm water
Field details	Field number and area (ha) correspond to farm map Yield (bales/ha) Key dates (planting, defoliations and picking) Irrigation (full or partial) and system (furrow, bankless, lateral move, pivot, drip or others) Row configuration (solid, skip row, double skip, single skip or others) Soil type (A, B, C, D)[3] Starting and end available soil water (mm or % PAWC) Other relevant information	Water accounting and ETc estimation. Yield calculation
Water storage information	Storage (name, area, capacity and s level at key events (end of previous session, start and end of current season	To calculate total water

[3] A - Sandy with a little silt or clay; B - Sandy or silty loam, or well drained alluvial; C - Self-mulching clays, clay loams, well-structure red loam; and D -Heavy clays such as grey cracking, sodic clays or hard-setting red clay loams

Water performance indicators for irrigated cotton and data analysis

Gross production water use index

The gross production water use index (GPWUI) is one of the measures of water use efficiency at the farm level. It is the standard measure of farm water productivity used in the Australian cotton industry. To ensure a consistent representation of long-term trends, we have continued to use the average GPWUI value as the industry benchmark, as supported by numerous studies (Tennakoon and Milroy 2003, Williams and Montgomery 2008, Montgomery and Bray 2010, Roth et al. 2013, Montgomery et al. 2014, Perović et al. 2019, and McLeod et al. 2022). Since 2021 we also report the 80th percentile or the GPWUI from the top 20% of farms studied.

GPWUI measures the number of bales produced from each megalitre (ML) of water used to grow cotton on a farm. It is a useful indicator of the potential profitability of the farm's water resource. GPWUI is calculated by dividing the cotton yield (in bales/ha) by the total amount of water available for cotton crops (in ML/ha) at a farm level and is expressed in bales/ML (Equation 1). One bale contains 227 kg of cotton lint. The total water used to grow cotton crop for a season used in this calculation includes irrigation water from various sources, effective in-crop rainfall, and stored soil water used by the crop for the season, but excludes water used to grow other crops (Tennakoon and Milroy 2003). The estimated of total water is described in Equation 2.

Equation 1. $$GPWUI = \frac{cotton\ yield}{total\ water}$$

Equation 2. $$Total\ water = Change\ in\ storage\ volume\ + metered\ water\ (river\ and\ bore)\ + effective\ rain\ + \ water\ harvested\ (FPH, rainfall\ runoff) + change\ in\ stored\ soil\ water - water\ used\ on\ other\ crops$$

Total crop water use and crop water use index

The total crop water use (Etc) is calculated using the NDVI estimated from satellite imagery using IrriSAT Technology. The crop water use index (CWUI) is calculated using total yield divided by total crop water use at the farm level for a given season.

Whole farm irrigation efficiency

Whole farm irrigation efficiency (WFIE) is an index that describes how efficiently irrigation water is being used at the farm scale. It indicates the proportion of irrigation water used by the crop in relation to the total irrigation water brought onto the farm during the growing season (Equation 3). It is an important parameter to evaluate the system efficiency in terms of irrigation losses during the growing season (Tennakoon and Milroy 2003).

Equation 3. $$WFIE = \frac{crop\ water\ use - effective\ incrop\ rain - soil\ water\ change}{total\ irrigation\ water\ brought\ onto\ the\ farm} \times 100$$

A high WFIE value indicates low losses from storage, transmission and field, and the crop has used a higher proportion of the irrigation water brought onto the farm. Tennakoon and Milroy (2003) suggested 60% as a critical level for WFIE. When it falls below this level, the system needs to be examined for potential improvement. The industry's target for WFIE is around 75% (Tennakoon and Milroy 2003).

Sustainable water use index

The sustainable water use index (SWUI) indicates the amount of water required to produce a unit of cotton lint (Equation 4). SWUI tells us how much water is needed to grow cotton, in either ML/bale or litres/kg. Essentially, a lower SWUI value indicates more sustainable water use. Buyers and consumers are increasingly interested in sustainable production (CRDC and CA 2020a,b) and SWUI is a suitable indicator for cotton sustainability. A low SWUI could help maintain and potentially improve the cotton industry's market access and social license.

Equation 4. $$SWUI = \frac{total\ water}{cotton\ yield}$$

Currently there appears to be a lack of global standard method for calculating a sustainable water use indicator. SWUI (Equation 4) can potentially be used to fill this gap.

Gross value of water productivity

For both irrigated and rainfed systems, the gross value of water productivity or GVWP (gross margin, $/ML) is calculated based on the published average value of cotton/bale for the season (i.e. Boyce Comparative Analysis for cotton, Boyce Report 2023). GVWP is expressed as gross AU$ output/ML of total irrigation water use on farm. This reflects the United Nations Sustainable Development Goal indicator 6.4.1. We used the standardised value of based on published gross margin sheet from.

Other water irrigation water performance indicators

A range of other water performance indicators are included in the report for each irrigated cotton farm (see example in Figure 2).

Other Farm Water Indicators		
Irrigation water use index (IWUI)	x	bales/ML
Gross value of irrigation water productivity (GVWP)	x	Gross AU$/ML
Crop water use index (CWUI)	x	bales/ML
	x	
Farm Water Summary		
	ML	ML/ha
Water from river/creek/bore/rainfall-runoff/FPH	x	x
Rainfall on storage	x	x
Change in storage volume	x	x
Water used to grow other crops	x	x
Total irrigation water	x	x
Effective rainfall on irrigated fields	x	x
Change in stored soil water	x	x
Total farm water input	x	x
Total crop water use (ETc)	x	x

Irrigation Water Summary			
	ML	ML/ha	% Irrigation water
Storage losses	x	x	%
Channel and drain losses	x	x	%
Operational losses	x	x	%
Field application losses	x	x	%
Irrigation water used by crop	x	x	%

Figure 2. Other farm's water performance indicators provided to the grower in their farm report. The definition of these terms is provided below

- Change in storage (dam) volume is the difference in storage volumes at the start of the season to the end of season.
- Change in stored soil water is the difference in stored soil water at the start and end of the season.
- Channel and drain losses is evaporation and deep drainage losses from supply channels and drains. estimated from wet surface area measured via remote sensing, and potential evaporation from weather data.
- Crop water use index (CWUI) is the total yield divided by total crop water use.
- Effective rainfall on irrigated fields is rainfall that infiltrated into the soil profile and was available to the crop.
- Field application losses are losses due to deep drainage when irrigating, which is estimated by solving the water balance equation (by difference).
- Harvested water is water harvested from flood plain harvesting (FPH) or overland flow and may include rainfall run-off as part of the licence. The value is estimate by the grower.
- Gross value of irrigation water productivity (GVWP) is Gross AU$ output/ML of total irrigation water use on farm. This reflects the United Nations Sustainable Development Goal indicator 6.4.1. For the 2023 season we have used the standardised value of $711/bale for one bale of irrigated cotton (see Boyce Report 2023).
- Irrigation water use index (IWUI) is total yield divided by total irrigation water applied.

- Licensed water is water extracted from rivers/creeks and groundwater under licence.
- Operational losses are water lost from through farm operations such as blow outs etc.
- Rainfall on storage is rain that fell directly on the storage over the season.
- Storage losses are evaporation and deep drainage losses from on farm storage(s).
- Total crop water use (ETc) is the total crop evapotranspiration estimated using IrriSAT Technology.
- Total farm water input is "The total seasonal water inputs from all water sources and includes water pumped from rivers and bores, the amount used from storage, water harvested during the season, rainfall and depleted soil water reserves. Soil water reserves can be from pre-season rainfall, pre irrigation or moisture stored during the fallow or previous crop. Water used on other crops is subtracted from the water input to the farm in calculating the farm water use efficiency for cotton" (Tennakoon and Milroy 2003).
- Total irrigation water is the sum of water inputs applied on farm to grow cotton and includes water from river/bore/irrigation scheme/rainfall runoff/FPH, rainfall on storage surfaces, and changes in storage volumes.
- Whole farm irrigation efficiency (WFIE) is the proportion of irrigation water used by the crop relative to the total irrigation water.

Water performance indicators for rainfed cotton

For rainfed cotton, the water productivity is expressed as the crop water use index (CWUI) calculated by total yield divided by the total crop water use. Project CRDC DAN2002 developed a simplified model to predict the water productivity of rainfed cotton in the absence soil water records as described in Equation 5.

Equation 5. $$WP_{rc} = CWUI = \frac{(bale * 227)\ kg\ lint}{PAWS_{0-100(sowing)} + Cum\ ER_{(sowing-defoliation)}}$$

Where, WPrc is the water productivity of rainfed cotton in kg/mm or bales/ML; PAWS is the plant available water storage in mm or ML, and ER is the effective rain in mm or ML. Full profile (100% PAWS is equal plant available water capacity of the soil (PAWC), measured or estimated. This model assumes that all plant available water storage is used by the crop at the end of the season.

The initial model proposed in CRCD DAN2002, the daily Effective Rain was estimated using the following formula (McLeod, unpublished):

ER= [(rain >5 mm) x 0.75], and capped at 50 mm

In the current DAN2303 project, a factor 0.7661 was used to convert total rain to effective rain (ER). This factor was derived empirically using the historical rainfall and effective rainfall relationship from the long-term benchmarking data.

When records of stored soil water (quantitative or qualitative) at sowing and defoliation are available, the water productivity is calculated as yield divided by the sum of ER and changes in soil water storage and is described in Equation 6.

Equation 6. $WP_{rc} = \text{CWUI} = \frac{(bale * 227)\ kg\ lint}{\delta PAWS_{(sowing-defoloiation)} + Cum\ ER_{(sowing-defoliation)}}$

In the absence of measured soil water, we have used the APSOIL profile site with the same soil type and closest to the farm to estimate soil PAWC. In the absence of similar soil type we used the rule of thumb method described in Burk and Dalgliesh (2013).

Equation 5 and Equation 6 were used to estimate water productivity of rainfed cotton farms surveyed from 2022/2023 and 2023/2024 seasons. For most farms, the soil water component was estimated using the combination of qualitative information provided by the growers and the estimated PAWC data obtained from ApSOIL. If the grower did not provide any soil water information it was assumed that the crop was sown at full profile, and it used all the available water at the end of the season (Equation 5).

Communication strategy

Project's activities and results are communicated regularly to all stakeholders as outlined in Projects Communication Plan (Appendix?). The benchmarking project requires intensive level of engagement with cotton growers throughout project's life from sample planning, data collection and processing, record verification and reporting processes. Annual results for individual farm are provided to growers in a tailored grower report in both preliminary and final versions.

Cotton REOs are engaged in the planning and implementation of data collection either through individual REO's network or through CottonInfo's newsletter.

Communication to both funders and partners (Cotton Research and Development Corporation, CRDC and NSW Department of Primary Industries and Regional development, NSW DPIRD) are conducted through formal Steering Committee meetings, progress and annual reports as well as informal meetings with the CRDC Program Manager.

The benchmarking project team also communicated to wider audience through various media platforms, presentation at local and international cotton events (i.e field days, Cotton Camps, Cotton Conferences and the Australian Cotton Research Conferences), as well as presentation to relevant government agencies representatives.

The project team actively communicated results to the scientific and public audiences through written publications. For example, NSW DPIRD Primefact, Australian Cotton Conference abstracts, cotton magazine articles or newsletters, and post cards.

Monitoring and evaluation

To understand how cotton growers value and benefited from the benchmarking project, we sought feedback from growers who previously participated during the data collection in 2024. The feedback was collected by asking grower too to answer five simple questions in Figure 3. In addition, informal feedback was also documented whenever we talked to grower.

Figure 3. Five questions to obtain feedback from growers

Would you be willing to answer 5 questions about your experience?								
1	How much benefit do you think you have obtained as a grower from participating in the project? [1-5]	HIGH	5	4	3	2	1	LOW
	Why? and what are the benefits?							
2	How much benefit do you think the industry has obtained by the project? [1-5]	HIGH	5	4	3	2	1	LOW
	Can you say what those benefits are?							
3	Was it easy for you to access your farm records (yield and water records) that the project is requesting from you? [1-5]	YES	NO	COMMENTS:				
4	Would you have any suggestion to make it easier for you to help us in providing your water record?							
5	5. Do you have any other comments about the project or issues associated with cotton water use and productivity? *(Eg. Is the water productivity report that we provide based on your data is useful/beneficial?)*							

Results and discussion

Monitoring and reporting of water productivity in irrigated cotton in the context of sustainable water use

Water productivity and irrigation efficiency

Gross production water use index (GPWUI)

Figure 4 illustrates a consistent upward trend in cotton water productivity from 1997 to 2007, followed by a plateau and marked seasonal fluctuations thereafter. Between 1997 and 2007, the annual rate of improvement in water productivity was approximately 8–9%. From 2007 to 2022, this rate declined to less than 1.0% annually, although productivity levels remained significantly above those recorded in 1997. Notably, between 2022 and 2024, the average GPWUI rebounded, showing an annual improvement rate of 6–8%.

The major gains between 1997 and 2007 were driven by enhanced varieties, better crop management practices and improved irrigation technologies. The plateau in productivity improvement after 2007 indicates diminishing returns from earlier innovations, and likely constraints on water availability given influence of seasonal rainfall. After these initial breakthroughs, further improvements became harder to achieve, as the industry approached the physiological and technological limits of current systems.

Over the 28-year period, the average GPWUI for Australian irrigated cotton increased from 0.62 ± 0.06 bales/ML in 1997 to 1.13 ± 0.04 bales/ML in 2024, with a long-term average of 1.07 ± 0.02 bales/ML. In the 2024 season, GPWUI values ranged from 0.57 to 1.86 bales/ML. The top 20% of participating growers achieved GPWUI values of 1.26 bales/ML or higher. The highest recorded average GPWUI was 1.22 ± 0.04 bales/ML in 2021, with the top 20% of growers that year reaching 1.41 bales/ML or more.

The benchmarking programs indicate that while long-term productivity has improved, seasonal fluctuations and external pressures have made consistent year-on-year gains more difficult.

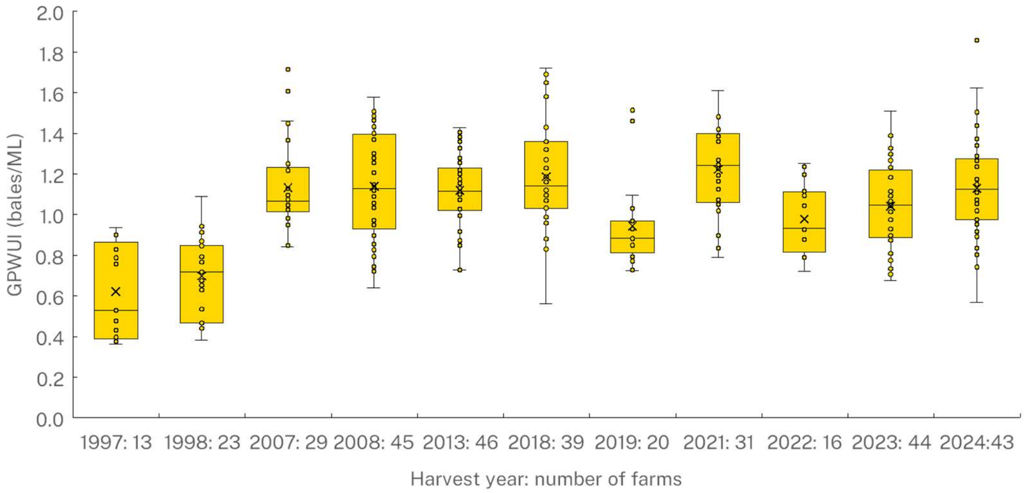

Figure 4. The average value of gross production water use index (GPWUI) and its distribution across irrigated cotton farms benchmarked between 1997 and 2024[4]. Data prior to 2022 was drawn using previous benchmarking results[5].

Seasonal impacts on water productivity

The seasonal fluctuation of the GPWUI has only been more visible after the yearly benchmarking commenced in 2018. However, no benchmarking was conducted in 2020 due to the continuation of the 2019 drought significantly reduced the cotton area. The following examples show how water productivity responded to varying seasonal rainfall conditions:

2019 drought conditions

During the drought of 2019 the average effective rain of 1.11 ML/ha (Figure 5d) was less than half the long-term average of 2.32 ML/ha. The average GPWUI decreased from 1.19 bales/ML in 2018 to 0.94 bales/ML (Figure 4). The drought conditions forced grower to increase the amount of irrigation water

[4] The boxes represent the interquartile range where the middle 50% of the data lie. The x in the centre of each box is the average value, and the bottom and top whiskers represent the data range excluding outliers. The horizontal line inside the box represents the median value

[5] Milroy 1996 — 1999 data (unpublished), Tennakoon and Milroy (2003), Williams and Montgomery (2008), Montgomery and Bray (2010), Roth et al. (2013), Montgomery et al. (2014), Perović et al. (2019), and McLeod et al. (2022)

to maintain crop growth. However, the additional water did not result in a higher yield due to the increased heat stress and atmospheric demand for water. As a result, the average cotton yield decreased from 12.23±0.31 bales/ha in 2018 to 11.39±0.56 bales/ha in 2019 (Figure 5a), despite the total water input rising from 10.21±0.34 ML/ha in 2018 to 11.37±0.53 ML/ha in 2019 (Figure 5d). The combination of reduced yield and increased water use led to a significant decline in GPWUI.

Wet season dynamics

In the wetter than average season of 2022, the average total farm water input exceeded that of 2021 (Figure 5d). The contribution of effective total rain to total water increased from an average of 2.84±0.12 in 2021 to 3.48±0.14 ML/ha in 2022, the highest recorded since 1997 (Figure 5b). Surprisingly, this increase in rainfall did not reduce irrigation volumes. Instead, average irrigation water applied rose by approximately 1 ML/ha, pushing total farm water input up by 31%, from 9.52±0.35 ML/ha in 2021 to 12.43±0.70 ML/ha in 2022 (Figure 5d). This was largely due to rainfall occurring predominantly early or late in the season, limiting its effectiveness during critical growth stages. With average yield remaining consistent with 2021 levels (Figure 5a), GPWUI declined from 1.22±0.04 bales/ML in 2021 to 0.98±0.04 bales/ML.

A more favourable seasons of 2023 and2024

The 2023 and 2024 seasons were more favourable than 2019 and 2022, with effective rainfall averaging 2.54±0.20 and 2.78±0.12 ML/ha, respectively (Figure 4b). Although yields were slightly lower than in 2022, total water input was reduced (Figure 5d), resulting in improved water productivity, GPWUI increased to 1.04±0.03 in 2023 and 1.13±0.04 in 2024.

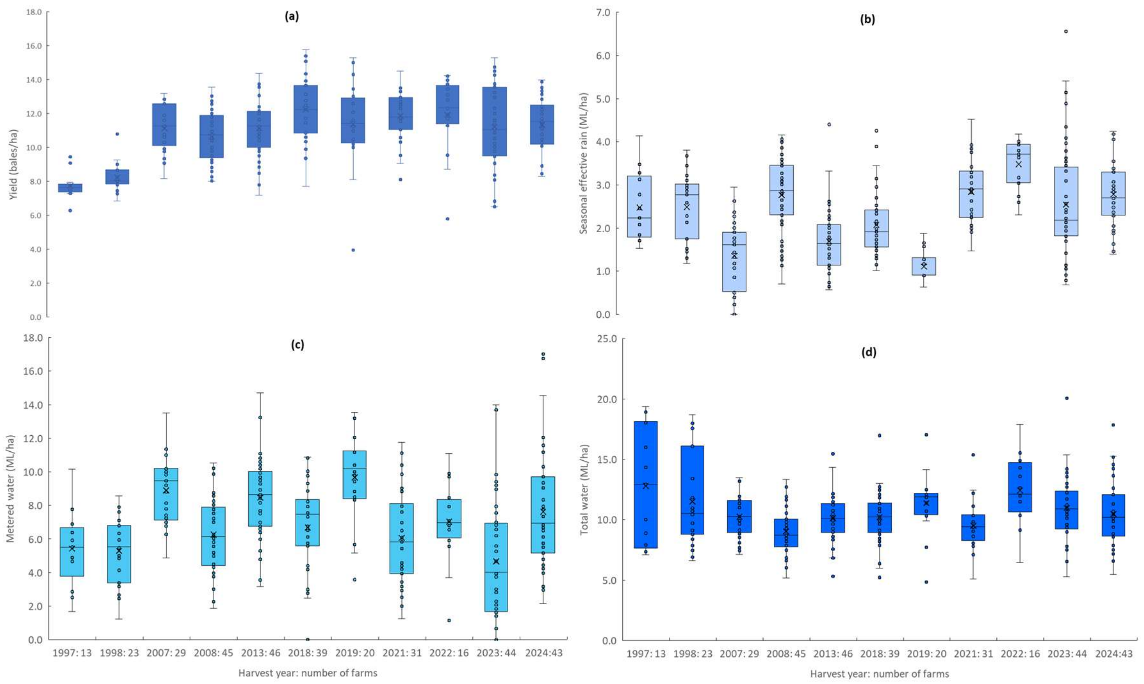

Figure 5. The long-term trends of average and distribution of irrigated cotton yield (a), effective rain (b), metered water (c) and total water (d) across farms sampled for benchmarking[4]. Data prior to 2022 was drawn using previous benchmarking results[5].

The significant decline in average GPWUI values in 2019 and 2022, compared with the higher values recorded in 2018, 2021 and 2024, highlights the vulnerability of cotton water productivity to climatic extremes. These downturns likely reflect the impact of droughts or floods, heat stress, or other adverse seasonal conditions that constrained crop growth and reduced water-use efficiency. Such variability underscores the importance of climate as a primary driver of water productivity outcomes, even in highly managed irrigation systems.

Encouragingly, the recovery in GPWUI observed in 2021, and again in 2023 and 2024, demonstrates the resilience of cotton production systems when favourable conditions return. This rebound suggests that productivity losses due to extreme events are not permanent but rather represent temporary setbacks. The capacity for recovery highlights the adaptability of Australian cotton growers, who combine technological innovation, irrigation efficiency, and responsive management practices to mitigate climatic risks.

Despite these fluctuations, the Australian cotton industry has maintained a world-leading position in water productivity, with a 25-year average of 1.07 ± 0.01 bales/ML. This long-term benchmark is more than double the global average of 0.48 bales/ML, based on the most recent international data available (Mekonnen and Hoekstra, 2011). Sustained performance at this level reflects not only favourable agro-climatic conditions but also systematic improvements in irrigation infrastructure, crop management, and industry-wide innovation.

These findings carry several implications. First, they reinforce the need for climate adaptation strategies that buffer against extreme events, such as investment in drought-resilient varieties, precision irrigation technologies, and climate forecasting tools. Second, they highlight the importance of maintaining industry-wide innovation pathways that have enabled Australia to achieve global leadership in water productivity. Finally, the contrast between short-term vulnerability and long-term resilience suggests that future research should focus on understanding the mechanisms of recovery, so that adaptive capacity can be strengthened further in the face of increasing climate variability.

Regional performance for water productivity

Each cotton-growing region in Australia has distinct characteristics in terms of soil types, climatic conditions, and cropping systems, all of which influence system design and present unique challenges for cotton production (Table 4).

Table 4. Characteristics of cotton growing regions*.

Region	Climate	Dependence on irrigation scheme	Growing season	Source of irrigation water	Use dams	Cropping systems	Rainfed cotton
Southern NSW (Lachlan, *Murrumbidgee* and Murray valleys)	Cool; shorter season, frost risk	High	October-May	Irrigation scheme	No	Cotton, rice, cereals, dairy	No
Northern NSW (*Namoi, Gwydir, Macquarie*, and Barwon-Darling)	Warm temperate; ideal for cotton	Moderate-high	September-April	Rivers, groundwater and flood plain harvesting	Yes	Cotton, sorghum, wheat, chickpeas	Yes

Region	Climate	Dependence on irrigation scheme	Growing season	Source of irrigation water	Use dams	Cropping systems	Rainfed cotton
Queensland (Darling Downs, St.George, Dirranbandi, Border Rivers/MacIntyre, and Central Queensland)	Warm-Tropical, longer growing season	Moderate	September-April		Yes	Cotton, sorghum, maize pulses	Yes
Northern Frontiers (Ord Rivers Irrigation Area, Gulf Region, Katherine-NT, **Douglas Daly**)	Tropical – sub tropical, variable rainfall	NA	Dec-August	Rainfall dependent; limited irrigation infrastructure	?		Yes

* The region name written in bolded italics are regions where benchmarking data were obtained from 2022, 2023, and 2024 seasons

Figure 6 and 7 illustrate the variability in yield and water productivity (GPWUI) across regions during the 2022, 2023, and 2024 seasons. These variations reflect the influence of regional characteristics, particularly seasonal climatic conditions. No single region consistently outperformed others across all three years, highlighting the importance of local weather patterns.

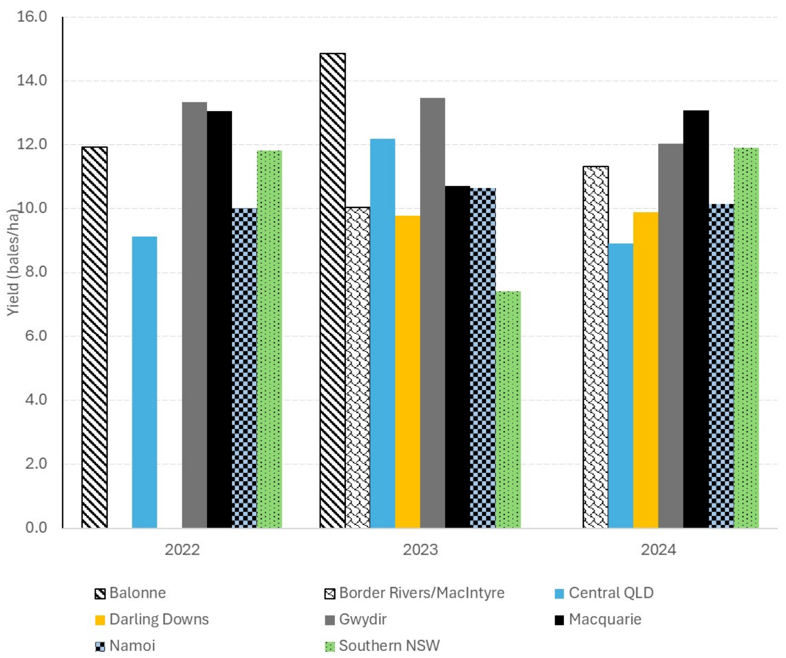

Figure 6. Average cotton yield (bales/ha) for different regions assessed for benchmarking in 2022, 2023 and 2024[6].

[6] The Balonne region only had one farm sampled in 2023, which had high yield but also had a high total farm water input, resulted in low GPWUI (Figure 7)

The Darling Downs region in Queensland is often noted for its consistently strong yields. This performance is attributed to its deep soils with high water-holding capacity and reliable seasonal rainfall.

However, productivity is not solely dependent on rainfall. Other climatic factors and disease pressures also play a role. For instance, in 2023, the Southern NSW region recorded lower GPWUI values compared to most Northern NSW and Queensland regions. Growers and consultants attributed this to an unusually cold and wet season, compounded by disease outbreaks. In contrast, the 2024 season saw improved yields in Southern NSW, which led to a corresponding increase in GPWUI.

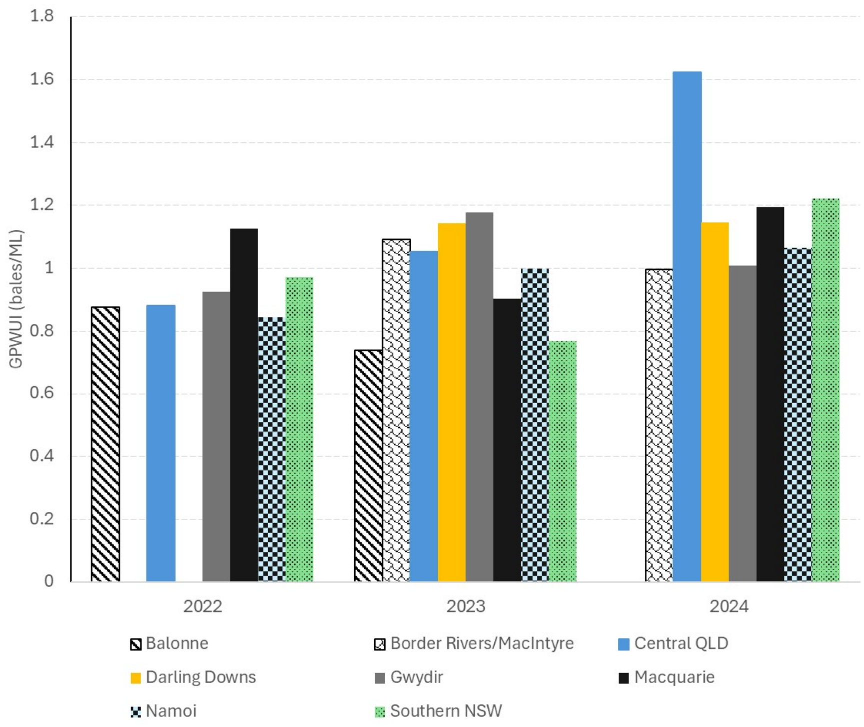

Figure 7. The average GPWUI for different regions assessed for benchmarking in 2022, 2023 and 2024[7].

How different sources of water relate to irrigated cotton yield in 2022, 2023 and 2024 seasons

Figure 8 illustrates the relationship between various water components and cotton yield across the 2022, 2023, and 2024 seasons. The data reveal a clear trend: yield increases with greater crop water use, irrigation water, and total water input, but not with rainfall, changes in stored soil water, or their combined contribution. This indicates that managed water inputs — particularly irrigation — are more effective in driving yield than uncontrolled sources such as rainfall or soil moisture fluctuations.

Key insights from Figure 8 include:

[7] In 2024, there was only one farm sampled from Central Queensland. The yield was not high, but the total farm water input was low, resulted in a high GPWUI (Figure 7).

Crop water use and yield correlation

Crop water use closely aligns with yield because it reflects actual plant transpiration (i.e. how much water the crop used for growth) {Sinclair, 2018 #12106}. (Sinclair 2018)

Precision of irrigation timing

Irrigation enables growers to deliver water precisely when the crop needs it{Owino, 2022 #12108} (Lina and Soffker 2022), especially during critical stages like flowering and boll formation. In contrast, rainfall is unpredictable and may not coincide with peak crop demand. While rainfall contributes to evapotranspiration (ETc), its benefit is less reliable and harder to quantify.

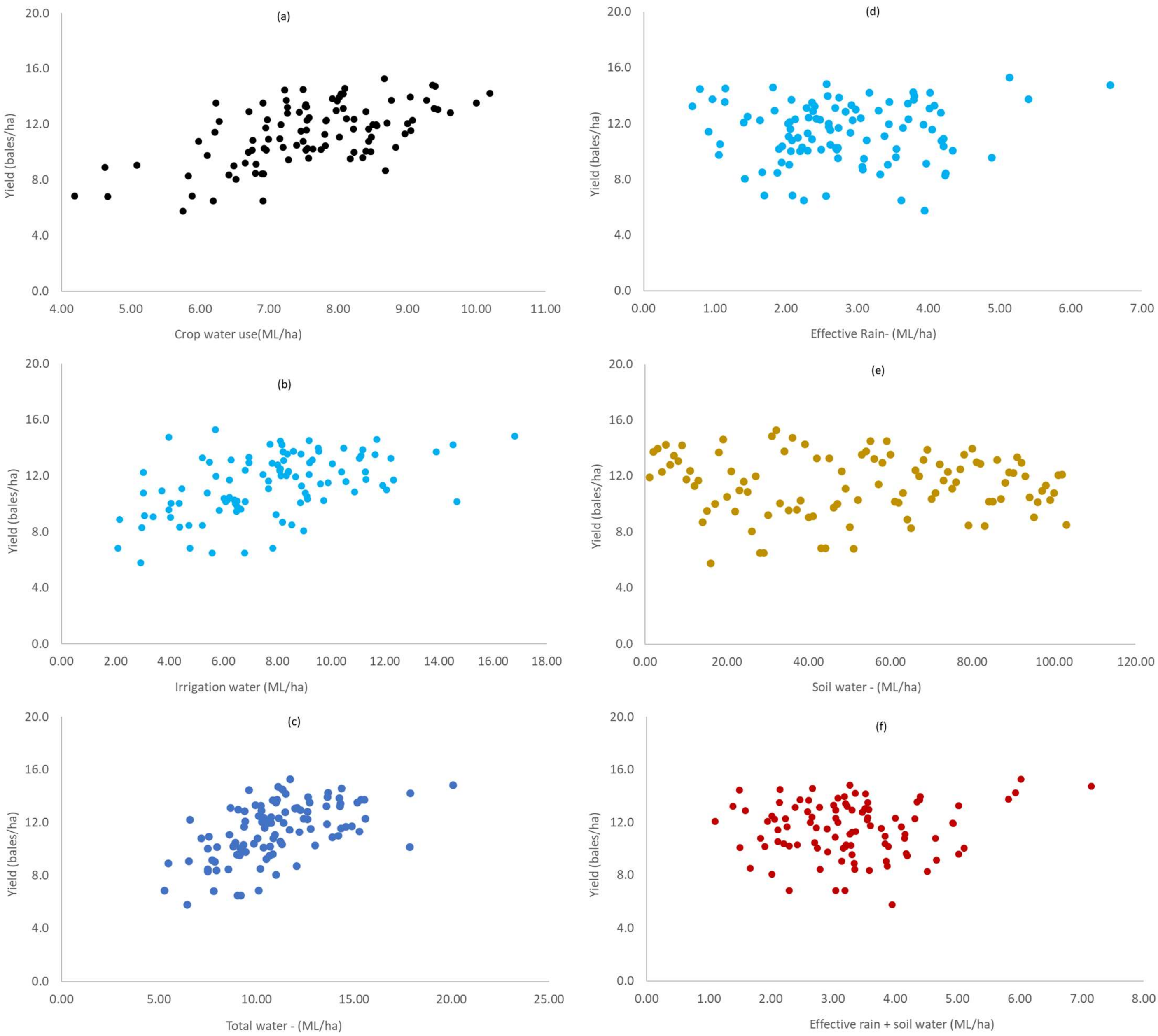

Figure 8. The relationships between different component or sources of water and cotton yield.

Consistency of irrigation

Irrigation provides stable water volumes, reducing plant stress and supporting uniform growth. Rainfall can be sporadic or insufficient, and stored soil water may be inaccessible if located too deep or unevenly distributed.

Avoiding water deficits

With irrigation, growers can prevent water deficits that would otherwise reduce yield. Unlike rainfall or soil water, irrigation is controllable and directly enhances ETc, particularly during dry periods.

Limitations of rainfall and soil water

Rainfall and soil water show weak correlations with yield. This is often because rainfall may occur outside the crop's peak water demand period or be lost to runoff and evaporation before benefiting the plant.

Soil profile constraints

The effectiveness of stored soil water depends on its depth and the soil profile. Water stored below the root zone is generally inaccessible, especially in soils with subsoil constraints.

Measurement uncertainty

Errors in estimating soil water content and changes can also obscure the true relationship between stored water and plant uptake.

This highlights the importance of strategic irrigation management over reliance on natural water sources. It reinforces findings from Australian cotton research showing that water productivity improves most when irrigation is optimised for timing, volume, and crop growth stage.

The relationships between yield, key farm water performance and water productivity indicators

Farm water productivity is calculated by dividing yield and total farm water input (Equation 1) so the pattern of relationships between yield and GPWUI (Figure 9a) and total farm water and GPWUI (Figure 9c) is as expected. Increased yield increases GPWUI but increased total farm water reduces it, but the relationships is not linear.

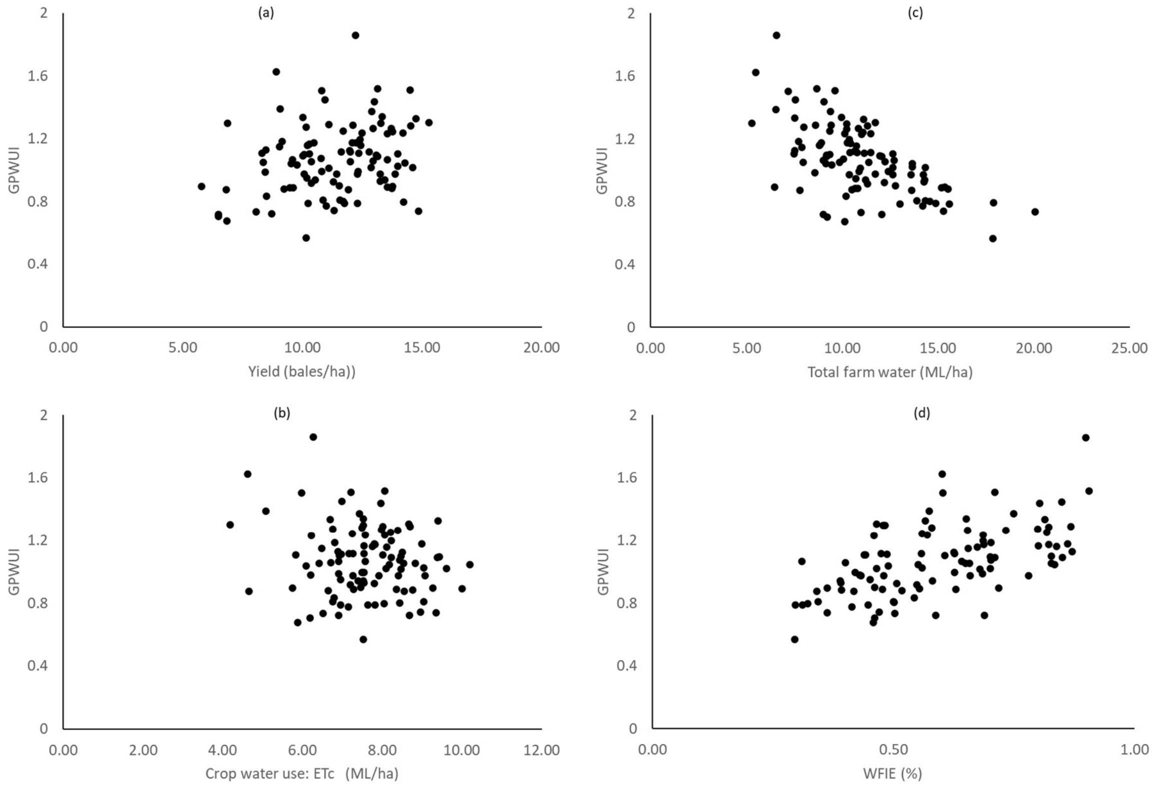

Figure 9 The relationships between different key crop and water performance indicators and water productivity in irrigated cotton.

While increasing yield generally improves GPWUI, the relationship becomes nonlinear due to diminishing returns and water-use inefficiencies at higher yield levels. As yield increases, each additional unit of water contributes to less yield gain. Early water application (i.e. establishment and flowering) usually more efficient than later application (i.e. during boll filling).

In addition, there is physiological limit for how much yield cotton crop can produce and once near this limit, more water does not translate into more yield gain. For cotton crop, ETc above 700 mm/ha usually does not translate into more yield (Tennakoon and Milroy 2003) and as it is reflected to some degree in Figure 9b.

High level of irrigation water application carries risk of water losses (deep drainage, evaporation and runoff) which are the source of inefficiency. Management that aims to maximise yield often involves more frequent irrigation, higher risk of waterlogging or disease and increased energy and labour costs and can result in reduced economic and water productivity.

Strategies to optimise GPWUI could include focusing irrigation on critical growth stage, avoid over-irrigation that adds little yield and the use of soil moisture monitoring and weather forecasting to refine timing of irrigation.

GPWUI shows a linear relationship with WFIE (Figure 9d) because they share the common numerator (yield) and both are affected by how effectively water is used to produce that yield. They also both have stable denominator relationships because in irrigated system, soil water and rainfall have relatively small contribution to total crop water use compared to irrigation water, which resulted in GPWUI and WFIE to behave similarly across farms or seasons. The linear correlation between WFIE and GPWUI reflects the dominance of irrigation in total water use and the shared yield numerator., but in systems with significant rainfall or soil water variability, GPWUI gives a more complete picture of water productivity.

Management factors affecting yield and water productivity

DAN 2303 was designed to assess water productivity at the farm scale, specifically through the Gross Production Water Use Index (GPWUI). While this was the primary objective, the dataset collected also provided an opportunity to conduct an exploratory field-level assessment of how different irrigation systems and crop management practices influence cotton yield. It is important to note that these findings are preliminary and would require a targeted research design to confirm performance outcomes with statistical rigor.

The exploratory analysis revealed several patterns listed below:

Irrigation intensity

McLeod et al. (2024) highlighted the potential for improving water productivity (GPWUI) by optimising both yield and water inputs, suggesting that high yields may be achievable with lower total water use through partial irrigation. However, this concept requires validation through specifically designed research that directly compares the water productivity of partially irrigated cotton with that of fully irrigated systems.

In the 2022–2024 benchmarking dataset, fully irrigated cotton consistently produced higher yields than partially irrigated crops (Figure 10a). This indicates that water availability remains a key driver of productivity and underscores the importance of effective and reliable irrigation scheduling. It is important to note that this benchmarking project can only compare yield outcomes between fully and partially irrigated cotton, not their GPWUI.

Irrigation system type

Evidence was insufficient to conclude that one irrigation system is definitively superior. However, there was a tendency for furrow irrigation to deliver higher yields compared to other systems (Figure 10b). This may reflect differences in water distribution efficiency or farmer familiarity with the system, but further controlled trials are needed.

Row configuration

Under irrigated conditions, cotton grown in a solid row configuration appeared to outperform skip row planting (Figure 10c). This could be linked to more uniform plant density and canopy closure, which may improve water use efficiency and reduce weed competition.

Sowing time

Earlier sowing within the growing season was associated with higher yields (Figure 10d). This finding highlights the importance of aligning crop establishment with optimal climatic conditions, particularly temperature and rainfall patterns.

Soil type

The dataset did not provide sufficient resolution to assess the effect of soil type on yield. This remains a critical gap, as soil texture and water-holding capacity are likely to interact strongly with irrigation practices. The absence of soil-type effects in this dataset underscores the need for future research designs that explicitly control for soil variability, as this could be a hidden driver of yield differences

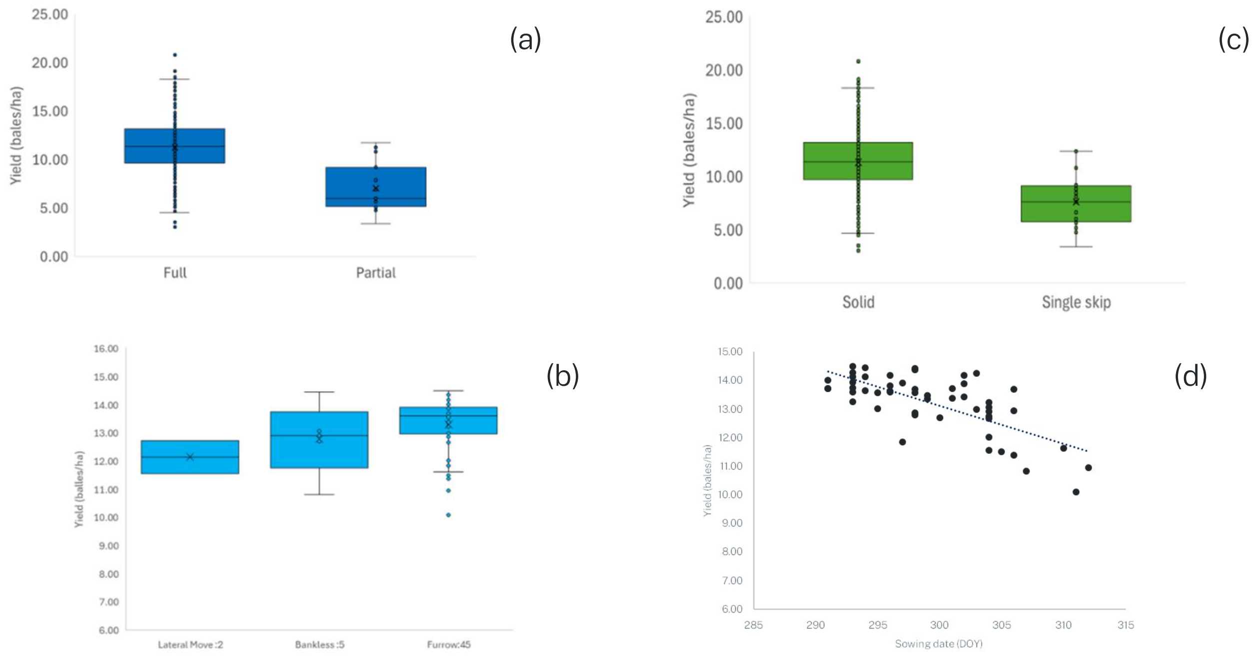

Figure 10. Preliminary assessment of irrigation systems and crop management impacts on cotton yield from 2022–2024 benchmarking

The results reinforce the dominant role of water availability in determining cotton yield, with full irrigation outperforming partial irrigation. While furrow irrigation showed promise, the lack of conclusive evidence suggests that system choice should be evaluated in context, considering local conditions, farmer expertise, and infrastructure.

Crop management practices, particularly row configuration and sowing time, emerge as potentially significant levers for improving yield under irrigated conditions. These factors may be easier to adjust than irrigation infrastructure, making them practical entry points for farmers seeking productivity gains.

Sustainable water use index (SWUI)

The Sustainable Water Use Index (SWUI) provides a measure of the volume of water required to produce one bale or one kilogram of cotton. In contrast to the Gross Production Water Use Index (GPWUI), which should be maximised, the SWUI should be minimised. A lower SWUI value indicates greater efficiency, as less water is required to produce the same unit of cotton.

Benchmarking results highlight notable year-to-year variability in SWUI. In 2021, the average SWUI reached its lowest recorded value of 0.84 ± 0.03 ML/bale (3,716 litres/kg), coinciding with the highest GPWUI (Figure 1). This alignment suggests that favourable climatic conditions and effective management practices can simultaneously enhance productivity and reduce water use per unit of output. By contrast, the wet season of 2022 saw SWUI increase to 1.05 ± 0.04 ML/bale (4,631 litres/kg), reflecting the influence of excessive rainfall and less efficient water use. Despite this increase, SWUI values remained substantially lower than historical benchmarks, such as the 1997 level of 1.84 ± 0.19 ML/bale (8,111 litres/kg). The subsequent improvements in 2023 (1.00 ML/bale) and 2024 (0.93 ML/bale) reinforce the capacity of the cotton industry to recover efficiency following climatic disruptions.

The long-term average SWUI from the 1997–2024 benchmarking program is 1.01 ± 0.02 ML/bale (4,460 litres/kg). This represents a remarkable achievement compared to the global average of 2.07 ML/bale equivalents (9,119 litres/kg) reported by Mekonnen and Hoekstra (2011). Such sustained efficiency gains reflect the combined impact of technological innovation, improved irrigation infrastructure, and adaptive crop management practices within the Australian cotton industry.

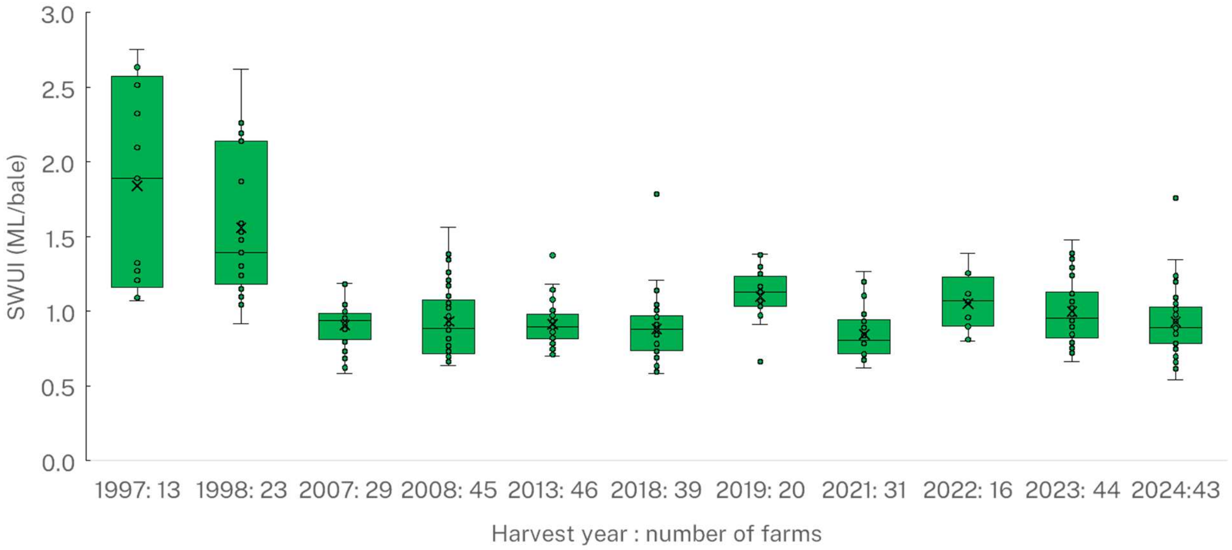

Figure 11. The average sustainable water use index (SWUI) and its distribution across irrigated cotton farms benchmarked between 1997 and 2024[4]. Data prior to 2022 was drawn using previous benchmarking results[5].

Taken together, the Gross Production Water Use Index (GPWUI) and the Sustainable Water Use Index (SWUI) provide a dual perspective on cotton water productivity. GPWUI highlights the capacity to maximise output per unit of water applied, while SWUI reflects the efficiency of minimising water use per bale or kilogram of cotton. The benchmarking results demonstrate that Australian cotton has achieved world-leading performance on both measures, combining high productivity with low water requirements.

The fluctuations observed across years underscore the sensitivity of water productivity to climatic variability, yet the long-term averages reveal a trajectory of sustained improvement. This dual achievement — maximising GPWUI while minimising SWUI — positions the Australian cotton industry as a global benchmark for sustainable water use in agriculture. Continued innovation, climate adaptation, and policy support will be essential to maintain this leadership and to further strengthen resilience in the face of future climatic challenges.

The broader sustainability context and implications of sustainable water use

The resilience and efficiency demonstrated by the Australian cotton industry align strongly with global sustainability frameworks such as the United Nations Sustainable Development Goals (SDGs). These findings contribute to SDG 6 (Clean Water and Sanitation) by showcasing efficient water use in agriculture, and SDG 13 (Climate Action) by highlighting the importance of adaptive strategies to manage climate variability. Moreover, the industry's leadership in water productivity provides a model for other agricultural sectors worldwide, reinforcing the potential for innovation-driven approaches to achieve both economic viability and environmental stewardship. By continuing to invest in climate-resilient practices, the Australian cotton industry not only secures its own future but also contributes to the broader global agenda of sustainable and climate-smart agriculture.

The sustained trend of SWUI have potential implications for:

Climate resilience

The fluctuations in SWUI highlight the vulnerability of water-use efficiency to climatic variability. Strategies such as precision irrigation, improved drainage, and climate forecasting tools will be critical to maintaining low SWUI values under increasingly unpredictable conditions.

Global benchmarking

Australia's long-term SWUI performance demonstrates that cotton can be produced with less than half the water required globally. This positions the industry as a global leader in sustainable cotton production, offering a model for other regions seeking to reduce agricultural water footprints.

Policy relevance

Sustained improvements in SWUI support national and international sustainability agendas, including the UN Sustainable Development Goals (SDG 6: Clean Water and Sanitation, SDG 12: Responsible Consumption and Production, and SDG 13: Climate Action). Policymakers can leverage these findings to promote water-efficient practices across agriculture.

Industry practice

For growers, the results reinforce the importance of management decisions — such as sowing time, row configuration, and irrigation scheduling — in achieving both productivity and efficiency. Continued investment in extension services and farmer training will be essential to translate benchmarking insights into widespread practice.

Future research

While long-term averages are encouraging, further research is needed to disentangle the effects of soil type, crop variety, and management practices on SWUI. This will enable more targeted interventions to sustain efficiency gains under diverse production environments.

Whole farm irrigation efficiency (WFIE)

WFIE trends, target and performance

The average WFIE values during the benchmarking program ranged between 45% and 83%. In 2022, the average declined sharply to 53% (Figure 12) before recovering in 2023 and 2024. No WFIE data were available for the 2019 season.

Irrigation efficiency depends on how water is used or lost, as outlined in Equation 3. Cameron and Hearn (1997, cited in Tennakoon and Milroy 2003) proposed a target average WFIE of 75% for cotton. This benchmark was exceeded in 2013 and 2018 (Figure 12), demonstrating the positive impact of strategies adopted by cotton growers to improve water use efficiency. However, flooding in 2022 caused the average WFIE to fall below the critical threshold of 60% suggested in Tennakoon and Milroy (2003). That year, crops used only 53% of the irrigation water applied, a significant decline from 61% in 2021 (Figures 3 and 4).

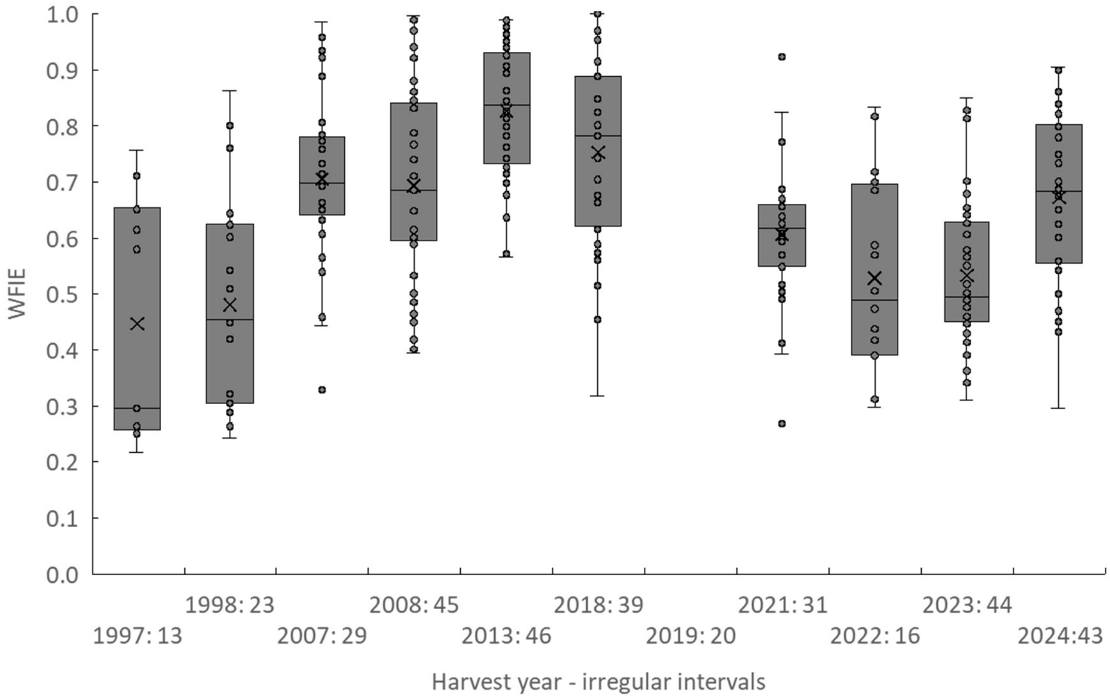

Figure 12. The average whole farm irrigation efficiency (WFIE) and its distribution across irrigated cotton farms benchmarked between 1997 and 2024[4]. Data prior to 2022 was drawn using previous benchmarking results[5].

Extreme weather events such as floods and droughts significantly disrupt irrigation efficiency in cotton farming, but growers can adapt through improved infrastructure, precision irrigation, and water management strategies.

Floods can wash away channels, damage pumps, and overwhelm storage dams, leading to unaccounted water input or losses and reduced WFIE. Flood can also make it harder to track irrigation volumes accurately, inflating field application losses. Floodwater can carry away soil nutrients, reducing crop uptake efficiency and requiring additional inputs.

On the other hand, droughts limit irrigation allocations, forcing growers to prioritise fields or adopt deficit irrigation strategies. Prolonged dry conditions reduce soil moisture retention, meaning more water is needed per hectare to achieve the same yield.

Growers can adopt a range of strategies to maintain efficiency under climate extremes. This could include using precision irrigation technologies using soil moisture sensors, telemetry, and automated scheduling help match water application to crop needs; drip and sprinkler systems have more potential to reduce losses compared to gravity-fed furrow irrigation; strategic irrigation at critical growth stages could conserves water while maintaining yield; infrastructure improvements to improve water distribution and reduce runoff, channels and storage losses; maximising soil infiltration capacity; flood plain harvesting when permitted, and crop management (i.e. sowing date and variety selection).

Sources of Water Loss

The largest losses in 2022 occurred during field application (32%), followed by storage losses (11%) and channel/tailwater losses (4%). By 2024, the average WFIE had rebounded to 64%, once again above the critical level (Figure 13).

Field application losses were estimated using the water balance equation for each farm. Any unaccounted water was classified as field application loss. Floods can damage irrigation infrastructure, leading to undetected losses, while wet conditions make accurate measurement of farm water use difficult. These factors likely contributed to the unusually high losses recorded in 2022.

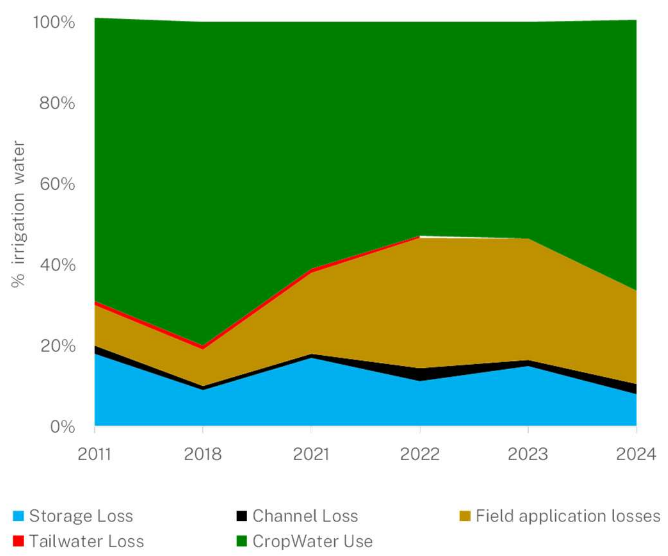

Figure 13. Irrigation water breakdown on cotton farm assessed for benchmarking between 2011 and 2024. Data prior to 2022 was drawn using previous benchmarking results[5].

As shown in Figure 13, partitioning irrigation water provides valuable insights into the sources of loss and highlights opportunities for improvement. During wet seasons, some growers may also benefit from high rainfall by carrying over unused irrigation water for later season.

Measuring, reporting and refining water productivity in dryland/rainfed cotton in the context of sustainable water use

We assessed 28 rainfed cotton farms during the 2023 harvest and 33 farms during the 2024 harvest (Table 1). The total bales produced by these farms represented 4.23% of the industry's rainfed cotton production in 2023 and 8.53% in 2024. For the 2024 harvest, results from one farm in the

Northern Territory were excluded from the reported average because the information obtained was insufficient to produce a reliable estimate of water indicator performances.

Model validation and yield potential for dryland cotton in each catchment

Equation 6 was applied to calculate crop water use and water productivity for rainfed cotton farms surveyed during the 2023 and 2024 harvests. Most farms did not directly measure or maintain records of soil water at sowing or harvest, nor did they have documented values for Plant Available Water Capacity (PAWC). Instead, they provided estimates of Plant Available Water at Sowing (PAWS) and at harvest, expressed as percentages of PAWC. To support these estimates, the nearest ApSOIL profile with a comparable soil type was used to approximate PAWS at the beginning and end of the season. The absence of measured soil data in rainfed cotton systems underscores the need for further validation of the water productivity estimates generated by the model.

When validated with measured soil water storage, this model will reflect variations across region as indicated by growing season, rainfall and soil types. Given the model's simplicity, there are several factors that may limit its accuracy, includes:

In the absence of measured plant available water storage (PAWS), the model assumes that all stored water in the profile is exhausted at harvest. This assumption may reduce accuracy when substantial rainfall occurs late in the season. Reliance on estimated PAWS values, rather than measured soil water data, introduces additional uncertainty. Similarly, the use of ApSOIL profiles as proxies raises questions about how representative they are of actual farm conditions. Nevertheless, the model's simplicity is also its strength, as it enabled the initial assessment to be undertaken.

Validation needs

Key field measurements required to validate the model include direct measurement of plant-available soil water capacity, the actual stored soil water in the profile between sowing and harvest, and on-site rainfall measurements. Ideally, these measurements should be collected across multiple farms located in different valleys or regions over several years. Such data will significantly strengthen model calibration.

We also found that rooting depth is an important factor to resolve when using PAWC values from the ApSOIL database. Obtaining a reliable estimate of the crop's active rooting depth will further improve model performance and validation.

Future directions

This initial assessment also highlighted the need to better understand atmospheric stress factors (i.e. heat stress or vapour pressure deficit) that influence the crop's ability to use water to produce lint. Incorporating remote sensing or sensor-based soil moisture monitoring, alongside other stress indicators, will help reduce reliance on estimated values.

Developing region-specific model calibrations is also necessary to improve accuracy. More importantly, exploring the relationship between water productivity and yield potential under climate-variability scenarios will be essential for advancing rainfed cotton productivity in Australia.

Annual water productivity of dryland cotton

The productivity indicators (Figure 14a) demonstrate a significant increase in the average rainfed farm yield, rising from 3.07 bales/ha in 2023 to 4.08 bales/ha in 2024. This yield improvement corresponds with the increase in effective rainfall, which rose from 146 mm in 2023 to 244 mm in 2024 (Figure 14b). The higher rainfall was accompanied by greater crop water use, increasing from 315 mm to 362 mm (Figure 14c).A marginal increase in average water productivity or CWUI from 1.01 to 1.13 bales/ML (Figure 14d) reflects the trade-off between yield gains and the additional water consumed. Further assessment is required to ascertain if the marginal increase in SWUI is sustainable given the rising water demand.

Rainfed cotton yield and water performance indicators varied considerably across farms in both years (Figure 15 and Figure 17. It is important to note that this is not a longitudinal study; farm numbers are specific to each individual year and should not be compared across years. Farms performing below the benchmark may be experiencing systemic constraints, potentially related to inadequate infrastructure, outdated agronomic practices, or environmental limitations.

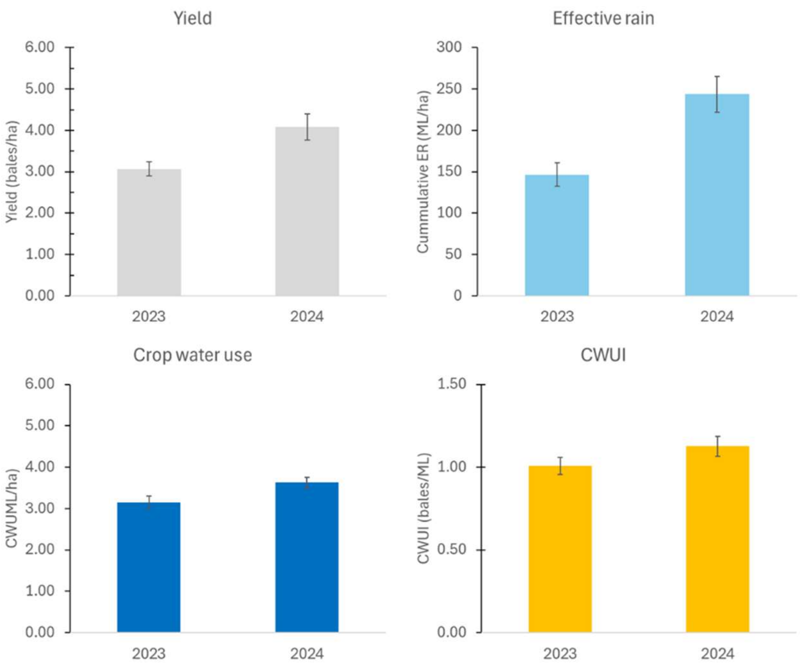

Figure 14. Yield, effective rainn, crop water use and crop water use efficiency of rainfed cotton sampled for 2023 and 2024 benchmarking.

Analysis of the benchmarking results shows that the top 20% of farms assessed in 2023 (six farms) achieved a CWUI of 1.18 bales/ML or higher, and in 2024 the top six farms achieved 1.49 bales/ML or higher. Despite their strong performance, there appears to be no consistent management strategy shared across these farms. Row configurations varied widely, including single and double skips as well as 2.4-metre spacing; PAWS levels ranged from 80% to 100%; and sowing dates spanned from early October through to late December. Notably, these same practices were also observed on farms with average and below-average CWUI, suggesting that the management variables captured in this dataset do not sufficiently explain the differences in water productivity. This highlights the need for a more targeted and detailed investigation into the underlying factors influencing CWUI, including potential interactions between soil characteristics, timing and distribution of rainfall, crop physiology, and on-farm decision-making.

In addition to the variability in management practices, the benchmarking results suggest that factors beyond the scope of the current dataset may be exerting a stronger influence on CWUI outcomes. Elements such as soil type, subsoil constraints, rainfall distribution, crop establishment uniformity, and in-season climatic conditions may be contributing to the observed differences between farms. The lack of clear patterns among high-performing farms indicates that water productivity is likely shaped by a complex interaction of biophysical and management variables rather than any single practice. This complexity underscores the limitations of relying solely on broad management categories when attempting to explain performance variation.

To address these knowledge gaps, a more targeted and detailed study is recommended. Such a study should incorporate finer-scale measurements of soil characteristics, effect of rainfall amount and distribution, crop growth dynamics, and decision-making processes throughout the season. Integrating these data with existing benchmarking information would enable a more robust analysis of the drivers of high CWUI and help identify the combinations of factors that consistently support superior water productivity. The insights gained would provide growers and advisors with clearer, evidence-based guidance for improving water use efficiency under a range of production conditions.

Overall, the findings from this benchmarking exercise highlight both the progress being made and the complexity of achieving consistently high-water productivity across farms. While top performers demonstrate what is possible under current production systems, the absence of clear, shared management practices indicates that deeper, more targeted investigation is essential. By improving our understanding of the underlying drivers of CWUI, the industry will be better positioned to support growers in making informed, evidence-based decisions that enhance water use efficiency and long-term sustainability

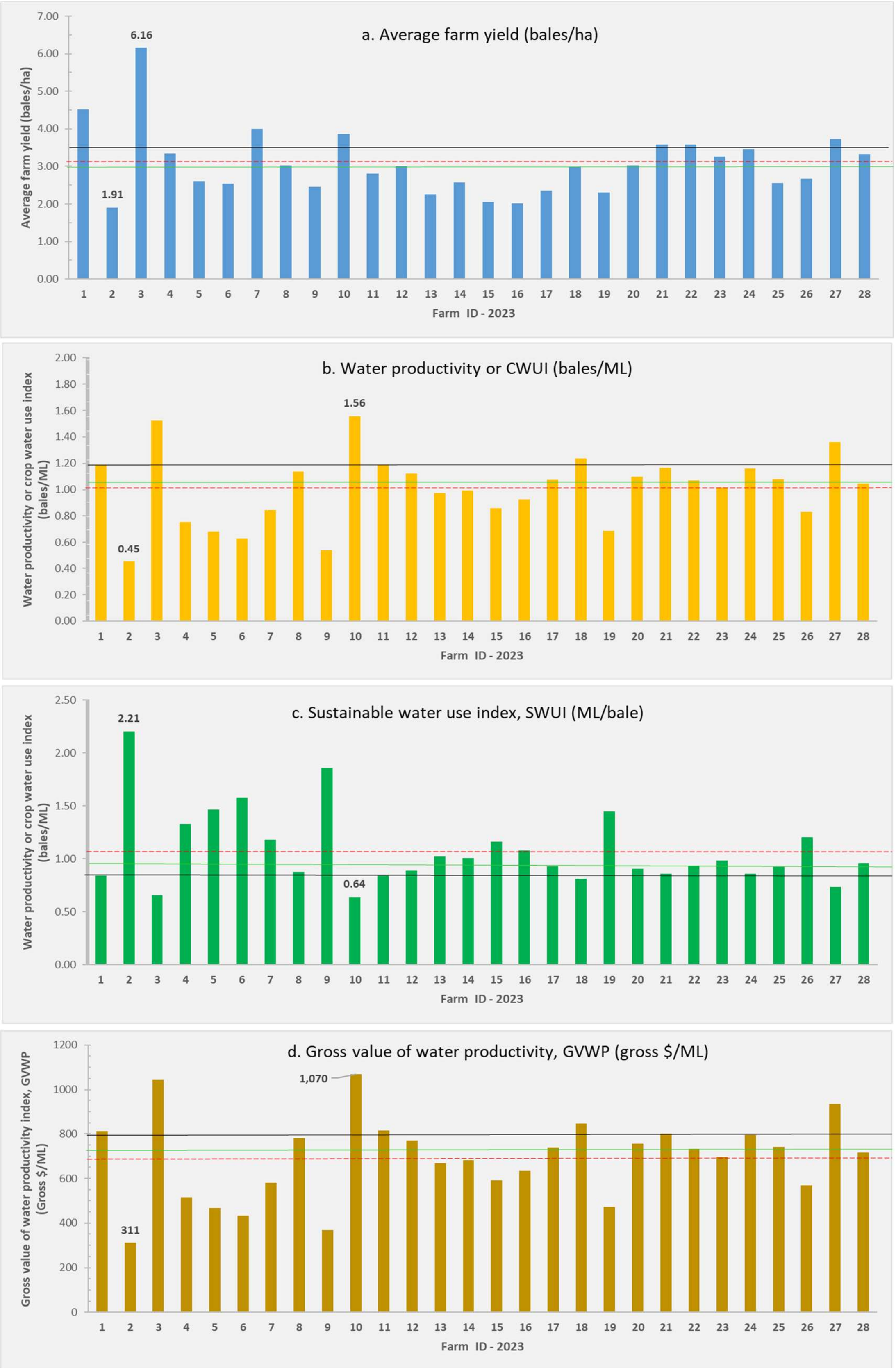

Figure 15. Yield (a), water productivity (b), water sustainability (c) and the gross value of water productivity (d) of rainfed cotton farms assessed in 2023 harvest. Red horizontal lines represent the average (red); the median (green), and the 80th percentile (black) values.

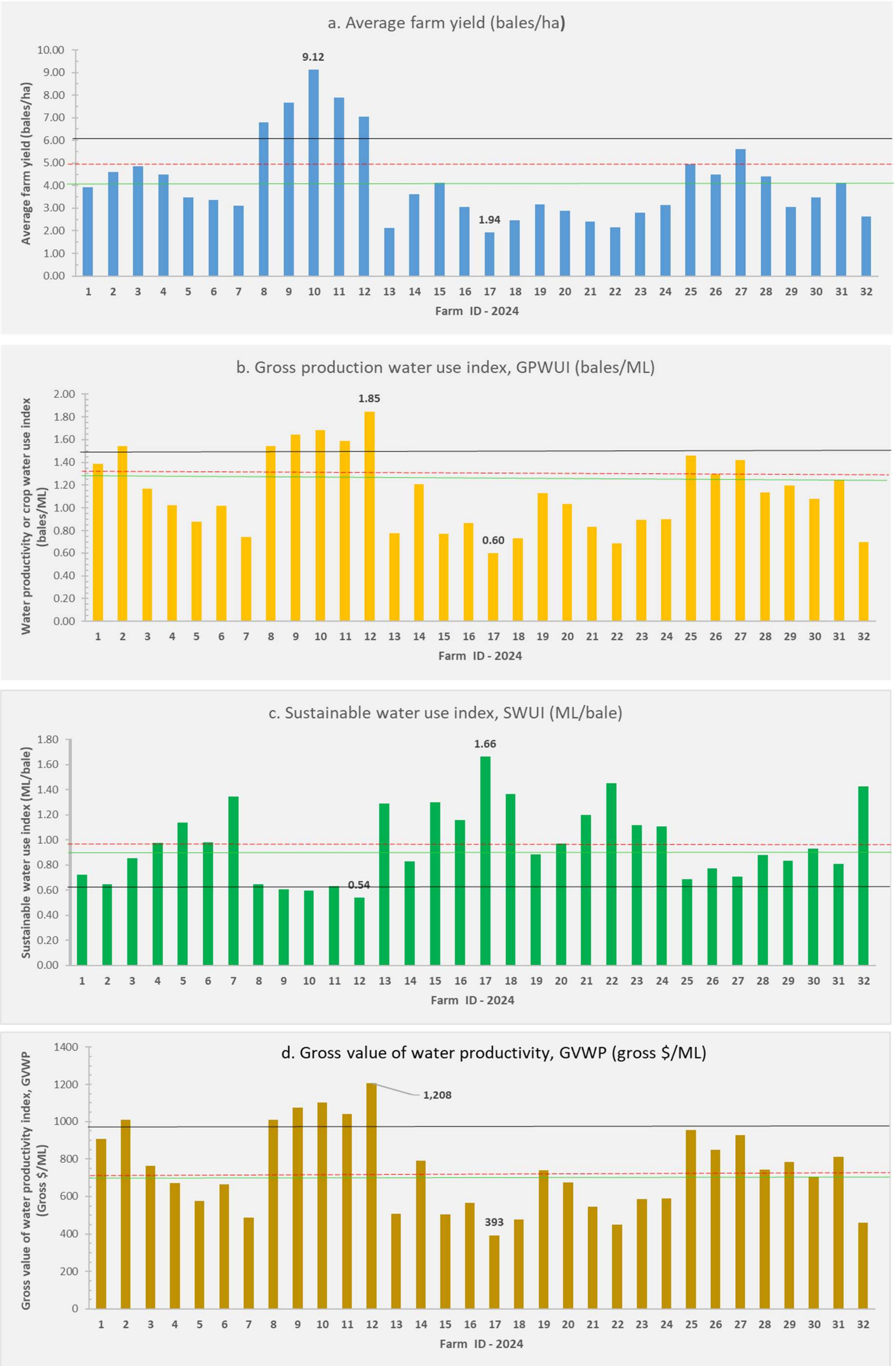

Figure 16. Yield (a), water productivity (b), water sustainability (c) and the gross value of water productivity (d) of rainfed cotton farms assessed in 2024 harvest. Red horizontal lines represent the average (red); the median (green), and the 80th percentile (black) values.

Strategies to improve the performance of below-average farms may include, but are not limited to: adjusting sowing dates, implementing precision crop rotations that maximise soil water storage for rainfed cotton, modifying row configurations, and adopting high-yield, water-efficient varieties:

Adjustment of sowing date

Planting at the optimal time helps align crop growth with rainfall and temperature patterns. Early or late sowing can reduce yield potential if crops face water stress or extreme heat during critical growth stages (ACPM 2025; CSD 2025; Anwar et al. 2020).

Crop rotation

Rotating crops strategically improves soil health and maximises water retention. For rainfed cotton, rotations with legumes or deep-rooted crops can enhance soil structure and reduce erosion, while also replenishing nitrogen (DCRA 2025; CottonInfo 2009; CottonGin 2025).

Row spacing

Altering row spacing or orientation can improve water infiltration, reduce evaporation, and optimise sunlight capture. It balances yield potential with water productivity. Narrow rows may increase plant density and yield, while wider rows can conserve soil moisture in dry conditions (CottonInfo online n.d; Bartimote 2014; Bange et al. 2012).

Variety selection

Switching to high-yield, water-efficient varieties is also critical in boosting yield and water productivity. Modern cotton varieties are bred for drought tolerance and higher productivity. Adoption of these varieties reduces risk under variable rainfall and supports sustainable production (CSIRO 2013) .

In short, boosting farm performance requires a mix of timing, soil management, spatial design, and genetic improvements. Together, these strategies help farmers make better use of limited water resources and adapt to climate variability.

Results by valley/region

Figure 17 and Figure 18 illustrate the variability in yield and water productivity (CWUI) of rainfed cotton across the regions sampled during the 2023 and 2024 seasons. These variations reflect the influence of regional characteristics, particularly seasonal climatic conditions. As with irrigated cotton, no single region consistently outperformed the others across both years, underscoring the strong influence of local weather patterns. This trend is evident in 2024, although it is less apparent in the 2023 dataset. The Darling Downs region in Queensland is frequently recognised for its consistently strong yields, a performance largely attributed to its deep soils with high water-holding capacity and relatively reliable seasonal rainfall. However, water productivity is not determined by rainfall alone; other climatic factors, soil conditions, and disease pressures or other stressors are also likely to contribute to the observed differences between regions.

In addition to the variability in management practices and regional conditions, the benchmarking results suggest that factors beyond the scope of the current dataset may be exerting a stronger influence on CWUI outcomes. Elements such as soil type, subsoil constraints, rainfall distribution, crop establishment uniformity, and in-season climatic conditions may be contributing to the observed differences between farms. The lack of clear patterns across regions/valleys indicates that water productivity is likely shaped by a complex interaction of biophysical and management variables rather than any single practice. This complexity underscores the limitations of relying solely on broad management categories when attempting to explain performance variation.

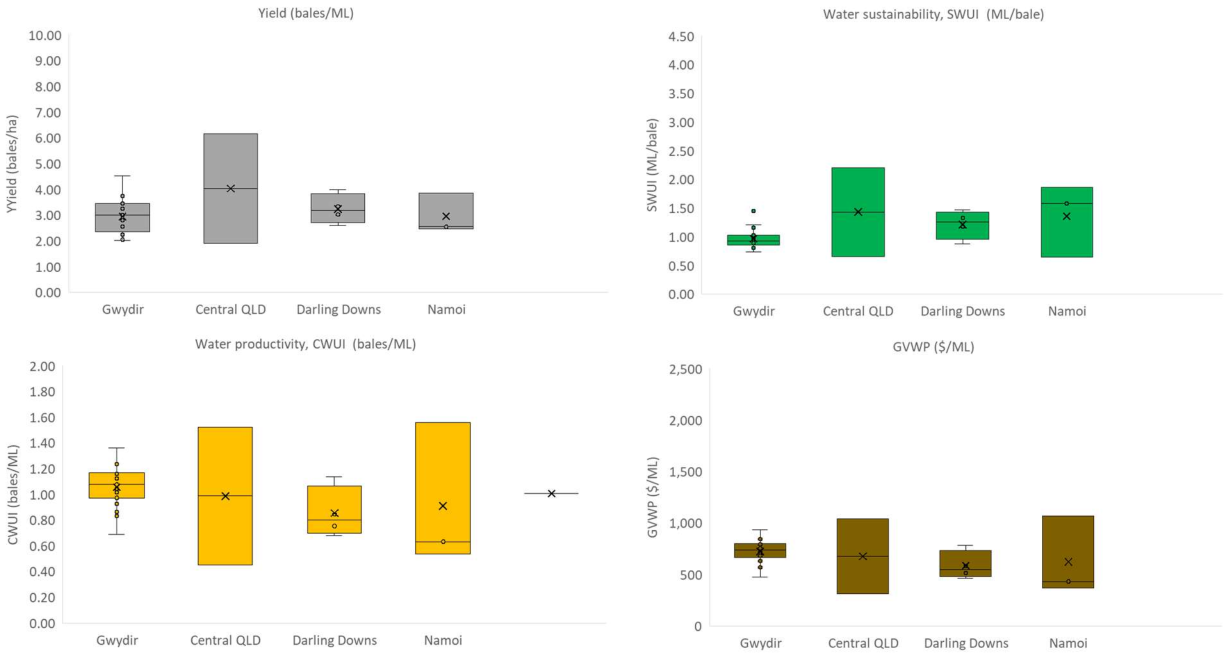

Figure 17 Rainfed cotton performance by valley for 2023 harvest

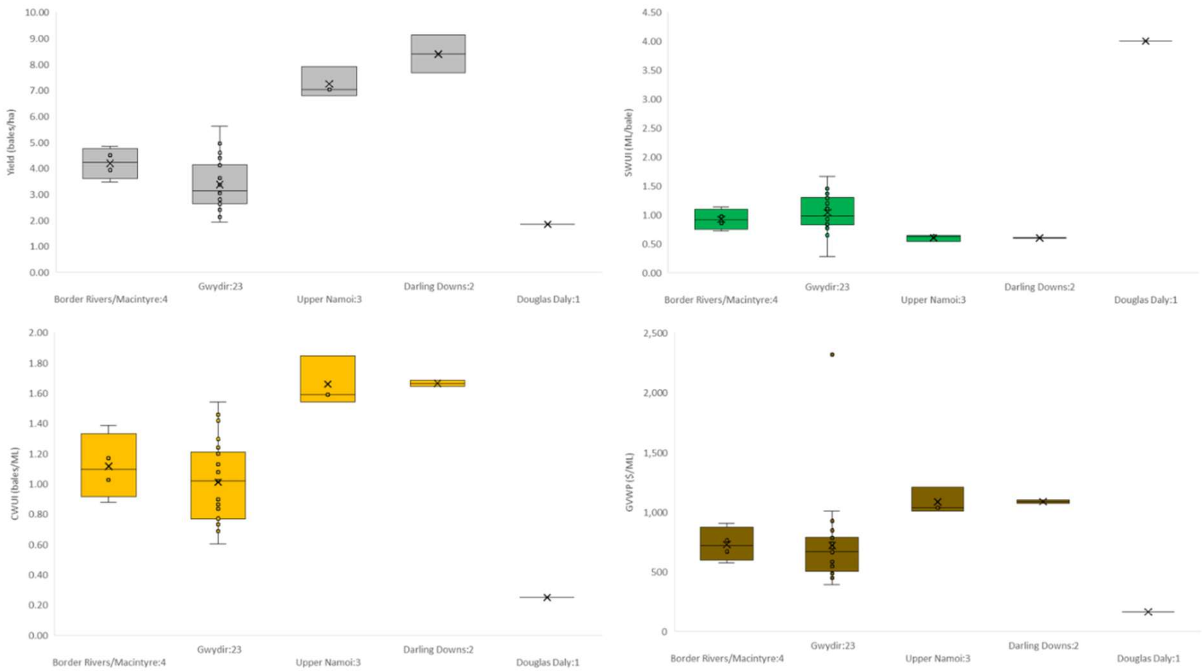

Figure 18. Rainfed cotton performance by valley for 2024 harvest.

Yield envelope and affecting factors

Figure 19 shows rainfed cotton yield as a function of seasonal crop water use based on the pooled data from 2023 and 2024. Crop water use was estimated from growers' assessment of start and end plant available soil water storage, combined with seasonal total effective rain.

The blue dotted line represents an arbitrary upper yield boundary for a given crop water use, with a slope of 2.15 bales/ha.ML and intercept of 1.174 ML. This boundary functions similarly to the yield-frontier concept described by French and Schultz (1984a) for wheat in southern Australia, where the line defines the maximum potential yield achievable for a given level of water use. The current slope value of 2.15 bales/ha·ML should be considered provisional; as more benchmarking data become available, this estimate may be refined.

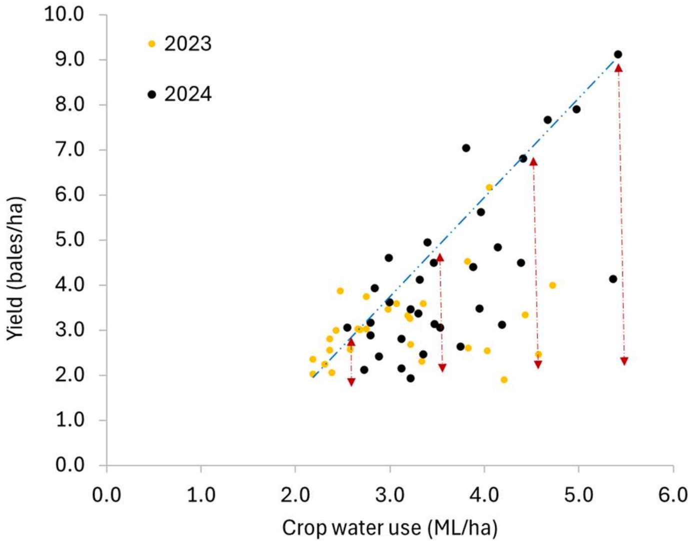

Figure 19. Scatter plot of rainfed cotton yield and seasonal crop water use. The arbitrary blue line uses French and Schultz (1984a) frontier concept for wheat, with x intercept = 1.17 ML and slope of = 2.15 bales/ha.ML

The yield boundary defines the maximum yield attainable for a given level of seasonal crop water use, while yields below this envelope highlight yield gaps reflecting the effect of management. While the benchmarking project was not designed to capture every factor affecting yield, the collected information on soil type, row configuration, and sowing date provides a useful starting point for understanding how these variables interact with crop water use and overall productivity.

Sowing date

Across the 2023 and 2024 seasons, rainfed cotton in the benchmarking dataset was established across a broad range of sowing dates rather than within a narrow, clearly defined planting window. When lint yield was plotted against the average sowing date, no consistent or meaningful trend was evident. Consequently, sowing date could not be reliably associated with yield performance in this dataset, and further analysis of sowing-date effects was considered inconclusive.

The absence of a clear relationship indicates that other production factors, such as fertiliser strategies, the timing and distribution of rainfall, and various environmental or management stresses, are likely played a more dominant role in driving yield variation.

Modelling studies, however, present a contrasting perspective. Bange (2025) identified an optimum sowing window for most regions between 15 October and 15 November based on average yield outcomes. Anwar et al. (2020) reported that later planting dates improved yield in drier regions where projected rainfall increases were more substantial. Similarly, Godfrey et al. (2023) found that late-October sowing, particularly under a solid-row configuration, tended to maximise lint yield. In comparison, most rainfed cotton in the benchmarking dataset was grown using skip-row systems or a 1.5 m solid configuration, which may limit the direct applicability of the modelling insights from Godfrey et al. (2023) to the observed field benchmarking results.

Row configurations

Figure 20 shows no consistent pattern indicating that any single row configuration produced the highest yields. The wide variation in yield within each configuration highlights the strong influence of other interacting factors such as soil type, rainfall timing, and management practices, on overall crop performance.

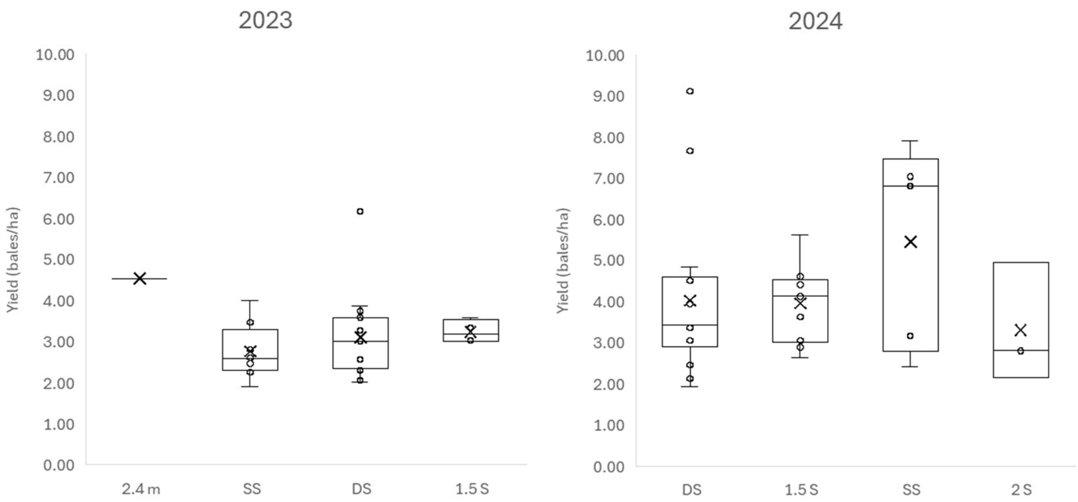

Figure 20. Rainfed cotton Yield response to different row configurations for 2023 and 2024 seasons. SS= single skip; DS = double skip.

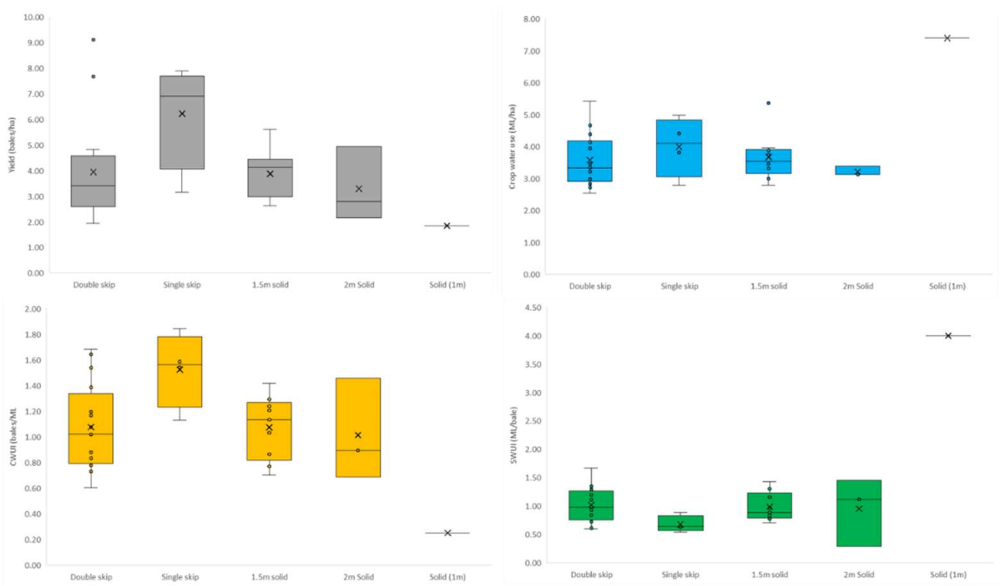

Figure 21. Cotton productivity performances in response different row configurations 2024 seasons. SS= single skip; DS = double skip.

For the 2024 season, specifically, the single-skip configuration tended to produce higher yields, which also translated into greater water productivity. However, this remains a preliminary observation based on a limited dataset and should be interpreted cautiously. More seasons of data are required before drawing broader conclusions or making recommendations.

While solid configurations are commonly used in irrigated cotton to maximise yield potential, skip-row systems are generally recommended for rainfed or limited-water situations. Skip-row arrangements increase the volume of soil and water available to each plant, and wider row spacing becomes increasingly advantageous as water availability declines.

CSD's Dryland Row Configuration Performance Tool supports growers in selecting the most appropriate configuration for their conditions. Rather than prescribing a single "ideal" row configuration for rainfed cotton, CSD advises growers to base their choice on regional characteristics, soil PAWC, rainfall risk, and planting date.

Rainfall distribution

The influence of rainfall on crop yield is determined not only by the total seasonal rainfall but, more importantly, by the timing and distribution of rainfall events throughout the growing season. Seasonal rainfall distribution is a critical driver of crop performance, as rainfall that aligns with key developmental stages can support growth and maximise yield potential, while poorly timed rainfall can constrain productivity even when total rainfall is adequate. This pattern has been observed across Australian cotton systems, where seasonal fluctuations in rainfall increasingly affect water productivity and yield outcomes (McLeod et al. 2024).

For cotton, the timing of rainfall is particularly significant. Early-season moisture is essential for uniform establishment and vegetative growth, while adequate mid-season rainfall supports square and boll initiation and reduces stress during peak flowering. Late-season rainfall influences boll filling and fibre development, with deficits during this period potentially reducing both yield and fibre quality. Conversely, excessive late-season rainfall can delay maturity and increase the risk of boll rot. These relationships are well documented in Australian cotton production, where rainfall during the summer months is a key requirement for dryland cotton performance, and where variability in rainfall and extreme weather events has been shown to strongly influence growth, development, and yield in dryland systems (Anwar and Darbyshire 2017).

In northern Australian cotton regions, rainfall distribution is even more critical due to the high variability associated with monsoonal and climate-driver-influenced rainfall patterns. These regions rely heavily on wet-season rainfall, making cotton production particularly sensitive to the timing and reliability of in-season rainfall events. As a result, uneven or poorly timed rainfall can have a substantial impact on cotton yield outcomes, independent of total rainfall received.

Soil type

Soil type is a major determinant of dryland cotton yield because it governs the soil's capacity to store and supply water, support root development, and retain nutrients. In dryland systems, where rainfall is the sole water source, soil characteristics often set the upper limit of yield potential. Understanding the interaction between soil properties and seasonal rainfall is therefore essential for predicting and managing yield outcomes. Crop simulation studies used in dryland planning also incorporate soil type and soil moisture as major determinants of yield potential (Bange 2025).

Deep, well-structured clay soils (Vertosols) have high plant-available water capacity (PAWC), enabling them to store large volumes of moisture and release it gradually to the crop. This buffering capacity is critical for sustaining cotton through dry periods during flowering and boll filling.

Most of soil types assessed in this benchmarking was soil type C (moderate plant-available water capacity (PAWC) and moderate structural limitations), and D (low plant-available water capacity (PAWC), significant structural limitations.

Soil structure influences root penetration and the crop's ability to access stored water. Deep, cracking clays allow extensive root development, improving the plant's capacity to extract moisture from depth. In contrast, soils with structural constraints such as compaction, sodicity, or shallow profiles, restrict rooting depth and reduce access to deeper moisture reserves.

The SOILpak manual for cotton growers (NSW Agriculture 1998) emphasises the importance of soil structure and identifies soil management issues that can limit root growth and reduce water-use efficiency in cotton systems.

Soil type affects nutrient availability and retention with clay soils typically have higher cation exchange capacity (CEC), supporting better nutrient retention and reducing the risk of nutrient loss. Sandy or low-CEC soils are more prone to nutrient leaching, which can limit early vegetative growth and reduce boll retention.

Soil type influences the geographic suitability of dryland cotton. Regions with deep clay soils and reliable summer rainfall such as parts of Queensland and northern New South Wales, are more favourable for dryland production. Cotton Australia notes that dryland cotton requires a full soil moisture profile and summer rainfall, conditions more easily met in areas with high-capacity clay soils (Bange 2025).

Fertiliser regimes

While information on fertiliser regimes was not collected in this benchmarking, nutrient management is known to have a major influence on rainfed cotton yield because nutrient supply interacts directly with rainfall, soil moisture, and crop growth timing. Manikandan et al. (2021) demonstrated that balanced and timely nutrient application improves boll retention, biomass production, and lint yield, whereas poor or mistimed fertilisation reduces yield potential, particularly under moisture-limited conditions.

These findings highlight the importance of capturing fertiliser regime information in future water-productivity benchmarking for rainfed cotton to improve understanding of the key drivers of productivity.

Atmospheric stressors

Rainfed cotton production is highly sensitive to atmospheric conditions because the crop relies entirely on natural rainfall and ambient climatic variability. A range of atmospheric stressors—including temperature extremes, vapour pressure deficit, radiation levels, and extreme weather events — directly influence crop growth, boll retention, fibre development, and overall yield performance. Recent climate research indicates that these stressors are becoming more frequent and intense across Australian cotton-growing regions, increasing production risk and contributing to greater yield variability (Broughton et al., N.D).

Key atmospheric stressors relevant to rainfed cotton include temperature extremes, high vapour pressure deficit (VPD), rainfall variability and extreme weather events, fluctuations in solar radiation and cloud cover, elevated atmospheric CO_2, and damaging events such as storms, wind, and hail.

Assessment of these atmospheric influences was outside the scope of the current benchmarking project. However, integrating atmospheric stressor data into future benchmarking efforts would substantially improve understanding of the climatic drivers of productivity in rainfed cotton systems.

Lessons learnt from benchmarking the water productivity of rainfed cotton

Rainfed cotton data collected from growers during the 2022/23 and 2023/24 seasons has enabled an initial assessment and quantification of water productivity in rainfed cotton systems and provided valuable insights that can be refined and expanded with further data and research.

The variation in yield, water productivity and sustainability indicators and the yield envelope generated from the benchmarking present a considerable scope for improvement through targeted management practices. The yield envelope indicates that factors beyond water availability are influencing outcomes and presents opportunities to identify and manage limiting factors and optimise agronomic practices. The yield envelope can be expanded with additional data from other regions and future seasons.

There is an opportunity to improve the current model for estimating water productivity by incorporating directly measured soil water data from each farm and by including relevant stress factors under limited water conditions.

Future research to quantify the effects of rainfall distribution on both yield and water productivity outcomes will increase understanding of its impact and inform adaptive strategies

Communication and engagement

The benchmarking project DAN2303 was actively promoted and communicated to stakeholders through industry newsletters and magazines, steering committee, progress and annual reports, industry events, grower and extension events, conferences, government agencies visits, presentations to students at DPIRD open days, contribution to Australian cotton production manual and project, the distribution of project postcards and presentation of three-dimensional displays.

Below are the list of communication and engagement activities conducted for the 2022 — 2025 period.

- Reports for 16 individual irrigated cotton farms for 2022, 46 Irrigated and rainfed farms for 2023, (and 54 for irrigated and rainfed farms for 2024 to be completed).
- Steering committee meetings (x6)
- Progress and annual reports to CRDC (x4)

- Cotton Australia's cotton camps (x2)
- Field days (x3)
- Spotlight article
- Grower association meetings (x8)
- Conferences presentations (x4)
- MDBA presentations
- NSW DPIRD's Primefacts (x2)
- Tamworth Agricultural Institute open day
- Presentation to students
- Australian cotton production manual (x2)
- Water productivity postcards

Monitoring and evaluation

The five evaluation questions were intended to gather and analyse growers experience and view about benchmarking of the Australian cotton water productivity as well as to assess required improvement in the process.

The response can be divided into five different themes:

1. Water productivity: Emphasising the importance of improving water productivity and the benefits of research and development in this area.
2. Data Management and Utilisation: Highlighting the need for better data management, timely data requests, and the use of hard data to defend industry practices.
3. Benchmarking and Comparison: The value of benchmarking farms and comparing water use efficiency across different irrigation types to identify areas for improvement.
4. Industry Contribution and Participation: The project's contribution to the industry and the importance of broader participation in data collection and reporting.
5. Challenges and Improvements: Recognising the challenges in data collection and reporting, and the need for streamlined processes and quicker report turnaround times.

Below is the detailed response from each of the evaluation question.

Question 1: How much benefit do you think the industry has obtained by the project? Can you say what those benefits are?

On the scale of 1 – 5 (1 being low and 5 being high), from 17 growers who are managing 24 farms is 4.06. Individual grower further comments are listed below.

- It is beneficial to the industry if it shows responsible water use
- It has a big benefit to the industry and needs to happen

- Measure water use efficiency
- The project provides hard data to defend industry
- High priority to show water savings.
- It is the biggest expense and supply is limited.
- Process highlights areas for improvement. It allows you to see where improvement is needed.
- I think the benefits would be higher if the data was circulated more.
- Its excellent for the cotton industry to continue to measure and monitor water use and to identify positive changes in terms of WUE particularly given the name cotton farmers get in terms of water consumption from the public and those who are unaware of how efficiently we now use water.
- The benefits are to acknowledge that the industry is complying and achieving better water usages for the future and still obtaining substantial yields
- (BLANK 9)

Question 2: How much benefit do you think you have obtained as a grower from participating in the project? Why? and what are the benefits?

On the scale of 1 – 5 (1 being low and 5 being high), from 19 growers who are managing 26 farms is 3.79. Individual grower response is listed further comments below:

- It is very helpful
- I already track water and budgets on 5ML/ha
- I am always striving to improve WUE and believe any R&D into WUE is beneficial.
- This project makes a contribution to industry.
- It provides data for industry to demonstrate responsible water use.
- It is useful to tool to compare - benchmark farms.
- It is a good exercise (to benchmark)
- Good thing to do and get results. Results need to come through sooner.
- Grower likes to measure crop (water) performance against peers
- Water efficiency data
- Good thing
- As a part of our management agreement with clients we provide firstly advice and management that is as efficient and reliable as possible and aim to provide results within a certain range of the industries performance; and secondly we provide accurate reporting and analysis. By knowing our performance within the region and industry it helps us to report back on our performance overall and reflect on it and propose changes identified.
- (BLANK 8)

Question 3: Was it easy for you to access your farm records (yield and water records) that the project is requesting from you?

On the scale of 1 – 5 (1 being low and 5 being high), from 19 growers who are managing 26 farms is 3.0?. Below are the individual further comments from individual growers.

- Shows record keeping deficits - most information required for Bayer audits.
- Reasonably easy, I know where they are it is a matter of sifting through and finding them.
- The project has streamlined the data collection process
- The project team makes it easy
- Yes, apart from Telstra and some technical issues
- Only because the data is available to us.
- It's not easy
- This is all the information we keep anyway, I think a lot of people would also have access to this information, so it is disappointing to put in the time and effort to see 3 or 4 other farms have participated in the data set for the valley.
- When records are kept up to date it is easy to access. Being from a small farm and being a very hands-on manager time is an issue.
- Blank (10)

Question 4: Do you have any suggestions to make it easier for you to help us in providing your water records?

- The storage meters will help with access to storage data and improved data management.
- The project provides hard data to defend industry
- Easiest in person
- Don't wait until the following summer. Request the data in July
- Fine
- Due to the nature of the cotton industry, we already participate in several surveys and data collection initiatives. I think you would get access to a larger number of farms if you 'piggy backed' into another group collecting all the same information, also if not the Agro doing it farmers themselves are too time poor (and sometimes stubborn) to sit and go through 5-6 different surveys and data collation points asking the same things. My self personally record this information as an Agro, its recorded by our area mangers and then analysts, it's also then recorded again by myself as the Agro to RivCott Gin - Sam Buster collects and analyses a lot of different data, I give it to Cotton Info, Crop Consultants Aus (CCA) also do a very large survey and anyone else who asks. The CCA one is so time consuming they subsidise people for supplying the information and are soon working with CSD I think it is to

collate all these different surveys and data so that we only have to do it once maybe it's something you reporting etc - at the moment they look like a lot of work goes into it and we can't really use it for much as we have moved onto the next reporting year. It would also be good to know some information on how each valley performed as well as a comparison of WUE of each irrigation type - this would help us in development phases in quantifying or justifying one system over another (ie siphon vs bankless, costs of pivot v bankless and the WUE savings etc).could go to them about and ask for irrigation data? I'm sure you'll have to figure something out about data sharing etc but might give you access to a much larger data set and confidence interval.

Question 5: Do you have any other comments about the project or issues associated with cotton water use and productivity?

- Farming water not specifically cotton - bales/ML is the metric for cotton.
- Farm operates on a forgiving soil type.
- Farm is focused on water productivity and producing the maximum number of bales for the available water.
- Rainfall is a curve ball in farming and irrigation management/scheduling
- The industry needs to get better at using the data that is collected.
- It is important R&D.
- Vital to know as 'crop per drop' becoming increasingly important.
- I have been a beneficiary of all the R&D before me, the least I can do is pay it forward.
- Important to focus on discussing irrigated crops not cotton.
- Cotton is a long season crop compared to other crops.
- It is good to benchmark, and for the industry to have the numbers.
- Critical for industry to have the numbers to support water use.
- The reports do take a long while to come back which is understandable but potentially if there is the capacity to get them out sooner (maybe if done in conjunction with the above) we could actually use the reports as a part of our annual reporting etc - at the moment they look like a lot of work goes into it and we can't really use it for much as we have moved onto the next reporting year. It would also be good to know some information on how each valley performed as well as a comparison of WUE of each irrigation type - this would help us in development phases in quantifying or justifying one system over another (ie siphon vs bankless, costs of pivot Vs bankless and the WUE savings etc).
- I think there is a lot to be done in this area in the future as from my own trials I have seen some very interesting results on water timing.

Additional anecdotal comments (not included – for more information please contact Sarah Dadd)

Overall conclusions

The CRDC DAN2303 project confirms that the Australian cotton industry has achieved world-leading water productivity and sustainability outcomes. Over the past 28 years, irrigated cotton has more than doubled its water-use efficiency, with GPWUI rising from 0.62 bales/ML in 1997 to 1.13 bales/ML in 2024, and SWUI averaging 1.01 ML/bale, less than half the global requirement. These improvements reflect decades of innovation in irrigation technology, crop management, and industry-wide collaboration.

Despite this progress, seasonal variability — driven by droughts, floods, and climate extremes — remains a major challenge, causing fluctuations in water productivity. However, the resilience and recovery observed in recent seasons demonstrate the adaptability of Australian cotton systems under favourable conditions.

Rainfed cotton benchmarking, introduced for the first time under this project, shows promising potential for expansion, with yields increasing from 3.07 in 2023 to 4.08 bales/ha in 2024, and CWUI improving from 1.01 to 1.13 bales/ML. Yet, performance variability across farms and regions highlights the need for targeted research into soil moisture, rainfall distribution, and stress factors.

Overall, Australia's leadership in water productivity aligns strongly with global sustainability goals (SDGs 6, 12, and 13). Continued investment in precision irrigation, climate adaptation strategies, and farmer training will be critical to maintaining this position and addressing future challenges. Benchmarking remains an essential tool for guiding improvements, supporting sustainability reporting, and strengthening the industry's social license and market access.

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List of industry and scientific publications, presentations, extension activities and other outputs

Table of Outputs reported between 2022-2025

May be incomplete list but they are all in progress and annual reports

Type of output	Description	Details
Reports		
	Contracted milestone report to CRDC-submitted	Progress Report 1 Submitted 30 November 2022 to CRDC via Fluxx (in CRDC system) Progress Report 2 Submitted 31 May 2023 to CRDC via Fluxx Progress Report 3 Nov 2023 Progress Report 4 May 2024 Progress Report 5 November 2024 Final Report – this report
Publications		
	6th Australian cotton research conference 26-68 August 2025, Narrabri	McLeod M and Dadd S. (2025). Benchmarking of water productivity and water sustainability of rainfed cotton in Australia. Presented at the 6th Australian cotton research conference 26-68 August 2025, Narrabri (Appendix 50)
	NSW DPI PrimeFact (2024)	McLeod M, Regan P, Dadd S, Uddin J and Harden S. (2024) Benchmarking indicates that Australian irrigated cotton has increased long-term water productivity despite its vulnerability to climatic extremes. DPI NSW Primefact PUB24/438. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/1559504/Benchmark-cotton-water-prod-Australia-2022.pdf
	Australian cotton research conference 5—7 September 2023, Toowoomba	McLeod M, Uddin J, Dadd S, Crawley B, Montgomery J, and Regan P. (2023). Water productivity and water sustainability indicators for Australian cotton - from the benchmarking program. Proceeding of 2023 Australian Cotton research Conference, page 28.
	Media publications	Press release prepared to encourage project participation and links with myBMP. Distributed as a Tweet on World Cotton Day (link?) Water benchmarking shows near 100% improvement. CRDC Spotlight magazine winter edition, page 8-9. https://www.crdc.com.au/sites/default/files/pdf/Spotlight%20Winter%202023.pdf

Type of output	Description	Details
		NSW DPI twitter (can't find the link)
	Primefact: Updated trends of cotton water productivity	Benchmarking water productivity of Australian irrigated cotton – 2021 results December 2022, Primefact PUB22/702, Revised second edition - Appendix 11 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0017/1441142/Primefact-Revised-19-Dec-2022-T-and-D-PUB22-702.pdf
	Media article – Grains & Cotton outlook	https://www.farmonline.com.au/story/8164957/cotton-growers-double-water-productivity-but-more-can-be-done/ - Appendix 12
	Cotton Innovation	Benchmarking water productivity of Australian irrigated cotton – the latest results (McLeod, Regan and Uddin) - Appendix 1
	IAL conference paper	Measuring Water Productivity and Efficiency of Irrigated Cotton – The process and 24 years of results (Crawley et al. 2022) – Abstract Appendix 2
	Completed and reviewed draft of a journal paper	Indicators of water productivity and water sustainability for irrigated cotton in Australia have doubled since 1997 – to be submitted to AWM (McLeod et al) Abstract Appendix 3
	REOs workshop by Water TechLead-CottonInfo	CottonInfo REO (Kieran O'Keeffe) published the description of the BM project in the Cotton Tale newsletter, edition November 2022 Water Productivity Survey Megan Woodward blog in CottonInfo website https://cottoninfo.com.au/blog https://cottoninfo.com.au/blog/water-productivity-benchmarking-how-you-can-be-involved
Presentations		
	6th Australian cotton research conference 26-68 August 2025, Narrabri	McLeod M and Dadd S. (2025). Benchmarking of water productivity and water sustainability of rainfed cotton in Australia. Presented at the 6th Australian cotton research conference 26-68 August 2025, Narrabri (Appendix 50)
	River reflection conference – Narrabri (14 — 15 June 2023)	Malem McLeod and CottonInfo Reo (Janelle Montgomery) presented the trend of cotton water productivity and water sustainability using the 3D display – Appendix 24 slide 17
	Australian cotton research conference 5 — 7 September 2023, Toowoomba	Water productivity and water sustainability indicators for Australian cotton - from the benchmarking program – Appendix 27 (power point presentation)
	Presentation to 43 individual growers (since August 2023)	Benchmarking project introduction, and description, and survey form to potential project's participants (SD and MM) – Appendix 28
	CGA meetings (September — October 2023)	Sarah Dadd or CottonInfo REOs presented the project at CGA meetings (Mungindi, Dirranbandi, St George and Upper Namoi)
	ACRI - Narrabri (18 September an 10 November 2023)	Presentation of irrigated cotton water productivity to 25 Australian Academy of Technological Science & engineering (ATSE) fellows on 18 September 2023 –Appendix 29 (invitation, program and photo)

Type of output	Description	Details
		Presentation of dryland cotton water productivity to scientists from Argentina (10 November 2023)
	Tamworth Field day (6 October 2023)	Sarah Dadd displayed and presented the 3D model of water productivity and water sustainability indicators at Tamworth Agricultural Institute open day attended by ~400 members of the public – Appendix 24 slide 19
	Meetings with CA sustainability program (multiple September/October 2023)	Contribution to the water sustainability framework (Teams meetings) – Appendix 24 slide 20
	Steering Committee meeting #3 (8 November 2023)	Presented Project update (MM) Appendix 24 (power point presentation) and Appendix 30 (word document)
	Four USA cotton scientists visit organised by CSD	Gunnedah, 8 March 2023: Handout - Appendix 13
	Three DCRA Field days	Verbal presentations by Malem McLeod and Sarah Dadd to a total of 96 audience over three field days In Ashley, Bellata and Toolluna, about the benchmarking project objectives, needs and benefits to the industry and growers . Summary document - Appendix 14
	Two CSD Field days	Verbal presentations to a total of >50 audience over two field days in Breeza (20 April-Sarah Dadd and Malem McLeod) and Coolah (27 April 2023-Sarah Dadd) about the benchmarking project objectives, needs and benefits to the industry and growers. Field days details and photos - Appendix 15.
	Cotton Australia Cotton Camp Tour 4 May 2023	Letter of invitation and detailed plan for presentation - Appendix 16a,b
	Project Steering Committee Meeting #2	Steering Committee Presentation file for project update - Appendix 17a and 17b (Malem McLeod, Sarah Dadd and Jasim Uddin)
	IAL conference: 4-8 October 2022	Presented: Measuring Water Productivity and Efficiency of Irrigated Cotton – The process and 24 years of results Crawley et al (title of presentation: Identifying the trends and drivers of water productivity in Australian cotton through benchmarking - DAN2002) Appendix 4
	An online workshop with CottonInfo REOs – 15 Nov 2022)	to introduce REOs to the new benchmarking project and discussed their role in supporting the project (Appendix 5: REOs presentation file)
	Report to individual grower	Example of benchmarking report sent to grower no 3: Appendix 6
	Survey question list for grower was updated during October 2022	Malem McLeod, Sarah Dadd, Ben Crawley and Jasim Uddin updated the grower question list to collect data to estimate GPWUI. The draft was workshopped with CottonInfo Tech Lead (Lou Gall) and REO (Janelle Montgomery) – Appendix 7
	Test run of the survey question list with grower: 7 November 2022	Sarah Dadd and Janelle Montgomery test run the survey question list with peter Lennox (Namoi)
New / updated standards		
	Improved BM survey form and datasheet	Excel spreadsheet (SD)

Type of output	Description	Details
	List of question for grower to collect water and yield data – BM	Appendix 7 (above): Can potentially be adopted in myBMP
	Data sharing agreement	A 3-way NDA between NSW DPI, WaterSENSE and CRDC – Appendix 8
	Project governance - Program Logic	Draft program logic for DAN2303 - Appendix 9
	Revised BM survey questions and JotForm link	Printable form - Appendix 18a, and Fillable form - Appendix 18b; online JotForm link https://form.jotform.com/230107748653861 (led by Sarah Dadd)
	Project Communication Plan	Outline what, how, when, and to whom project outputs will be disseminated - Appendix 19
Training and learning programs		
Products		
	Improved version of the 3-D water productivity and water sustainability model	Provide a visual display of trends for water productivity (bales/ML) and water sustainability indicators (litres/kg lint) since 1997. A picture of the model and of it being used to communicate the trend of cotton water productivity are presented in - Appendix 24 slide 19. This model has been used for a display at the CRDC stand at the MDBA River Reflection Conference in Narrabri, 14-15 June 2023; by CottonInfo REO team (Janelle Montgomery team) at the Cotton Collective & Trade Show, Toowoomba, 1-3 August 2023; and TAI open day display (SD)
	New index for water sustainability	SWUI now produced as an index alongside and complementing GPWUI
	GPWUI and WFIE values for 2022	GPWUI from benchmarking survey is completed (Jasim Uddin). However the sample size is <2% of the industry and it is not sufficient to represent the industry. On the other hand, the CRDC GS data, with a much larger sample size, is likely to have overestimated the GPWUI value because it does not count for inefficiency in the wet season of 2022 - Appendix 17b
	GPWUI report for individual grower for 2022	Example in Appendix 20 (Jasim Uddin and Malem McLeod)
	Project Postcard	Provide a broad description of the benchmarking project and its key results to attract readers to visit the project website and publication (click-baiting) by Sarah Dadd and Malem McLeod - Appendix 21
	3-D model of water productivity and water sustainability indicators	Provide a visual display of trends for water productivity (bales/ML) and water sustainability indicators (litres/kg lint) since 1997. A picture of the model and of it being used to communicate the trend of cotton water productivity are presented in - Appendix 22. This model is to be upgraded for display in the CRDC stand at the MDBA River Reflection Conference in Narrabri, 14-15 June 2023
	GPWUI for individual farm for 2020-2021 season	GPWUI results sent to grower ID 3: Appendix 6 (above)

Table of outcome reported between 2022-2025

May be incomplete list but they are all in progress and annual reports

Type of outcome	Description	Details
Extension services and training accessed		
	Interactive 3-D model	Partners are seeking to use the 3D model in their cotton promotions and displays, further promoting sustainable water use of cotton.
Increased knowledge about practices and products		
	Interactive 3-D model of water productivity & sustainability indices	Partners are seeking to use the 3D model in their cotton promotions and displays, further promoting sustainable water use of cotton (i.e. the use of the display by CottonInfo team in Cotto Collective and Trade Show August 2023, Toowoomba).
	Increased knowledge of CottonInfo REOs about the value proposition for the water productivity benchmarking	Introduction of the BM project to REOs conducted on 15 Nov 2022 has improved REOs understanding about the value of the project to individual cotton grower and to the industry (Appendix 5 above)
	Increased knowledge for cotton growers and industry about the benchmarking project and its benefits to individual growers and to the industry	CottonInfo REO (Kieran O'Keeffe) published the description of the BM project in the Cotton Tale newsletter, edition November 2022 : Water Productivity Survey Megan Woodward bog in CottonInfo website:https://cottoninfo.com.au/blog https://cottoninfo.com.au/blog/water-productivity-benchmarking-how-you-can-be-involved
	Increased knowledge for irrigated and rainfed cotton growers, other cotton researchers, advisers and industry about the benchmarking project and its benefits to individual growers and to the industry	Project presentations at: Three DCRA field days in Ashley, Bellata and Toolluna attended by a total of 96 rainfed cotton growers, advisers and other scientists (Malem McLeod and Sarah Dadd) CSD's field days: Upper Namoi Cotton Grower of the Year (Malem McLeod and Sarrah Dadd) and Coolah Field days (Sarah Dadd)
	Increased knowledge, awareness and appreciation of domestic and international supply chain members	Presentation on cotton water productivity benchmarking project at the Upper Namoi Cotton Grower of The Year (20th April) has resulted in Malem McLeod being invited to the Cotton Australia Cotton Camp to over 50 domestic and international supply chain members in Narrabri (4 May). The 3D

Type of outcome	Description	Details
	that use Australian cotton for their brands	display of water productivity and water sustainability indicators that Malem used for this event has attracted a further invitation to present them at the CRDC/CottonInfo stand for the MDBA River Reflection Conference in Narrabri, 14-15 June.
	Increased knowledge, awareness and appreciation of internal NSW DPI stakeholders about cotton water productivity and water sustainability indicators	As above + internal and external NSW DPI social media posting about the presentation in the Australian Cotton Camp Tour NSW Ag Water Tweet: https://twitter.com/NSWDPI_AgWater
Adoption of practices and products including behaviour change		
	Adoption of GPWUI for myBMP level 3	Collaboration with Rob Crothers, Warwick Waters and Mick Bange
Adoption of research findings, methods, and techniques by other researchers		
	Cotton water sustainability reporting. Planet. People. Paddock	The calculation methods used by the project to derive Water productivity and water sustainability indicators are used in the cotton sustainability framework (Chris Cosgrove)
	Cotton water sustainability reporting. Planet. People. Paddock	The BM project is the main source of information for water productivity and water sustainability reporting by Australian cotton Industry bodies Cotton Australia: a sustainable cotton industry – Fitzroy Partnership for River Health Aussie cotton industry aiding shift towards sustainable fashion - ABC News The Australian Cotton grower magazine Vol 44 (Aug-Sept 2023 edition) https://www.crdc.com.au/sites/default/files/Water%20-%20July%202023.pdf
	WA (Ords River) WP research	WA research group is seeking to use the method for calculating GPWUI in the ORIA WUE research
	The REO workshop has resulted in CottonInfo plan for online webinar for participating growers	After the REOs workshop, CottonInfo is planning to conduct online workshop for participating grower to demonstrate how benchmarking data can be used to increase farm income relative to the average grower by increasing individual farm GPWUI

Type of outcome	Description	Details
	Improved tools to conduct BM data collection method	Updated list of questions to collect grower data is used by the industry (CRDC GS 2022) and updated BM survey question list
Commercial agreements made		
Collaboration		
	DPIE Water (new)	Potential collaboration with Azeem Khan on farm water balance model using the WaterSENSE's dashboard (Dr Azeem Khan, Lead Remote Sensing, Water Analytics | Department of Planning and Environment)
	WA (Ords River) WUE (new)	WA research group is seeking to use the method in the ORIA water benchmarking study for cropping systems (cotton and other crops) – Improving water use efficiency in the Ord River Irrigation Area lead by Dr. Chris Schelfhout (DPIRD, WA)
	ACRI-Narrabri	Dr Guna Nachimutu is regularly inviting the presentation of cotton water productivity to visiting scientists
	CSD: James Quinn, Mick Bange and Chris Teague, Emma Lambeth and Nick Stewart	CSD provides data to BM project for irrigated and rainfed cotton data at field scale for all recent BM projects Field days, grower network and scientists visit Literature discussion
	WaterSENSE: Brian Jackson, Jelle Degen and Joost Braumbacher	Development of Water Balance dashboard for irrigated cotton -fortnightly meeting
	DCRA: Annette McCaffery	Potential source of rainfed cotton data from DCRA's led Dryland cotton project (March 2022 – June 2023) - Contribute to DCRA project development and provide inputs on research options to improve WP of rainfed cotton Access to rainfed cotton grower networks DCRA/CottonInfo rainfed cotton grower field days
	CottonInfo: REOs, Water TechLead and Warwick Waters	Cotton grower network DCRA/CottonInfo rainfed cotton grower field days Other public events involving cotton and water productivity (i.e. MDBA River Reflection)
	DAN2203: Sarah Dadd	Ensuring strong connection across the two projects ; Planning for joint steering committee meeting; Shared resources and partners
	Cotton Australia Sustainability Program: Chris Cosgrove	Providing SP with GPWUI and water sustainability indicators Chris Cosgrove provide feedback and also a member of the Project Steering Committee.
	CSIRO Plant Breeding Program: Warren Conaty and Lucy Egan	Collaborative presentation at the Cotton Australia 2023 and 2024 Cotton Camps
	MyBMP: Rob Crothers	GPUWI is now included in myBMP level 3
	GoannaAg: Alicia Garden	Access to probe data (grower data) for irrigated and to probe data and canopy temperature sensor data? for rainfed cotton

Type of outcome	Description	Details
	CSD: James Quinn, Mick Bange and Chris Teague	CSD provides data to BM project for irrigated and rainfed cotton data at field scale for all recent BM projects
	Enhanced collaboration with WaterSENSE: Brian Jackson	Development of Water Balance dashboard for irrigated cotton and the development of effective rainfall calculation method for the Namoi valley Fortnightly - meeting
	A stronger collaboration with DCRA: Annette McCaffery	Potential source of rainfed cotton data from DCRA's led Dryland cotton project (March 2022 – June 2023) Contribute to DCRA project development and provide inputs on research options to improve WP of rainfed cotton
	Collaboration with DAN2203: Sarah Dadd	Ensuring strong connection across the two closely related projects Planning for joint steering committee meeting Shared resources and partners
	Enhanced collaboration with CottonInfo: Lou Gall	Engaging with CI teams on the results of benchmarking and on gaining grower's participation in current and future benchmarking + increasing grower involvement in BM
	Maintained collaboration with Cotton Australia Sustainability Program: Chris Cosgrove	Providing SP with GPWUI value Advice on metric of WS metric for cotton (rainfed and irrigated)
	Revived and Maintained collaboration myBMP: Rob Crothers	To work towards including farm level GPWUI as the requirement of myBMP certification (Janelle Montgomery suggested level 2 is appropriate)
	New collaboration with Bayer/Goanna Ag: Kate Connors	Providing list of data required to generate GPWUI with a view to BM gaining access to additional data from their grower survey/trials
Industry capacity building		
	3-D model for WP and WS	Increased capacity of REO to communicate about water to cotton growers (i.e. the use of the display by CottonInfo team in Cotto Collective and Trade Show August 2023, Toowoomba)
	Improved capacity of individual cotton grower participating in BM to set new target for farm water productivity	Results sent to grower contain key water productivity and yield data that grower can use to change their business decision
	Improved capacity of REOs to support cotton grower	REO could use results from BM to provide water management and water productivity scenarios and their respective benefits to individual grower
	Improved capacity of individual cotton grower participating in BM to set new target for farm water productivity	Results sent to grower contain key water productivity and yield data that grower can use to change their business decision

Type of outcome	Description	Details
	Improved capacity of REOs to support cotton grower	REO could use results from BM to provide water management and water productivity scenarios and their respective benefits to individual grower

Appendices attached to this final report

Appendix 50. Presentation file: 6th Australian Cotton Research Conference 2025, Narrabri

List of appendices have already submitted to CRDC (not attached to this final report)

- Appendix 1 Benchmarking water productivity of Australian irrigated cotton the latest results.pdf
- Appendix 2 Measuring water productivity and efficiency of irrigated cotton- the process and 24 years of results.pdf
- Appendix 3 Indicators of water productivity and water sustainability for irrigated cotton in Australia have doubled since 1997.pdf
- Appendix 4 Identifying the trends and drivers of water productivity in Australian cotton through benchmarking - DAN2002.pdf
- Appendix 5 REO presentation Benchmarking overview Nov22 - notelessFinal_0.pdf
- Appendix 6 Example of BM results sent to grower-for REOs.pdf
- Appendix 7 Question list for grower to collect water and farm data for BM.pdf
- Appendix 8 RDOC22 213247 WaterSENSE NDA with CRDC , eLeaf and DPI signatures.pdf
- Appendix 9 Draft Program Logic for water productivity benchmarking in Australian cotton Industry DAN2303.pdf
- Appendix 10 RDOC22 246381 SC meeting 1-DAN2303 Water Productivity Benchmarking in the Australian cotton Industry.pdf

- Appendix 11- revised Primefact-Revised-19-Dec-2022-T-and-D-PUB22-702 (1).pdf
- Appendix 12 - farmonline.story-cotton-growers-double-water-productivity-but-more-can-be-done.pdf
- Appendix 13 - McLeodM_US Scientists meeting with CSD.pdf
- Appendix 13 - McLeodM_US Scientists meeting with CSD.pptx
- Appendix 14 - Summary of Dryland Cotton Management Field Days.pdf
- Appendix 15 - CSD Field days.docx
- Appendix 16a- Invitation to present at Cotton Australia 2023 Cotton Camp Tour Narrabri.pdf
- Appendix 16b - Detailed plan for Cotton Camp Presentation.pdf
- Appendix 17a - RDOC23 100288 SC meeting 2-DAN2303 Water Productivity Benchmarking in the Australian cotton Industry.docx
- Appendix 17b - RDOC23 100288 SC meeting 2-DAN2303 Water Productivity Benchmarking in the Australian cotton Industry.pdf
- Appendix 17b - RDOC23 100288 SC meeting 2-DAN2303 Water Productivity Benchmarking in the Australian cotton Industry.PPTX
- Appendix 18a - Benchmarking Word Doc - PRINTABLE FORM.docx
- Appendix 18b - Benchmarking Word FILLABLE FORM.docx
- Appendix 19 - RDOC22 246615 CommPlan_CRDCDAN2303 _Benchmarking Water Productivity.DOCX
- Appendix 20 -Grower report- BM2122_MAQ_Gainsford_Water_Central FarmPro_GPWUI.pdf
- Appendix 21 - Project DAN2303 Postcard.docx
- Appendix 22 - 3D model of GPWUI trend as images.docx

Appendix 24-DAN2303 Update for Steering Committtee meeting #3_20231108.pptx

Appendix 25-evaluation questions.docx

Appendix 26-AACS 2023 Proceedings.pdf

Appendix 27- Malem McLeod-AACS2023_ToowoombaRDOC23 182467.pptx

Appendix 28-BM22-23 Benchmarking - PRINTABLE FORM.pdf

Appendix 29-presentation to ATSE fellows Narrabri.pdf

Appendix 30 -RDOC23 248553 SC meeting 3-DAN2303 Water Productivity Benchmarking in the Australian cotton Industry-update.docx

Appendix 31-Table of Milestones Outputs Outcomes DAN2303-20231108.docx

Appendix 32-Primefact-Benchmark-cotton-water-prod-Australia-2022 .pdf Supporting Evidence ωTop Added by Malem McLeod at 1:09 PM on 30 May 2024

Appendix 33-Sample_BM2223 Individual report to grower.pdf Supporting Evidence Added by Malem McLeod at 1:09 PM on 30 May 2024

Appendix 34-Table of Milestones Outputs Outcomes DAN2303-20240529.docx Supporting Evidence Added by Malem McLeod at 1:08 PM on 30 May 2024

Appendix 35-Update for DAN2303 Water Productivity Benchmarking in the Australian cotton Industry-SC4.docx Supporting Evidence Added by Malem McLeod at 1:08 PM on 30 May 2024

Appendix 36-Dan2303 Update for Steering Commitee meeting4-20240515.pdf Supporting Evidence Added by Malem McLeod at 1:06 PM on 30 May 2024

Appendix 37- CampCotton 2024.docx Supporting Evidence Added by Malem McLeod at 12:45 PM on 30 May 2024

Appendix 38-MDBA board_IMG20240228151905.jpg Supporting Evidence Added by Malem McLeod at 12:44 PM on 30 May 2024

Appendix 39_Example of report to grower_BM2223_Irrigated

Appendix 40_Example of report to grower_BM2223_Rainfed

Appendix 41-RDOC24 201109-M5_AGENDA DAN2303 _SteeringCommitteeMeeting#5

Appendix 42-M5 Attachment 2-Update for DAN2303 Water Productivity Benchmarking in the Australian cotton Industry_20241113

Appendix 43-RDOC24 214131 M5_Meeting minutes DAN2303 _SteeringCommitteeMeeting5

Appendix 44_M5_DAN2303 Presentation Update for Steering Committee meeting #5_20241114

Appendix 44b. Regional averages with revised labelling

Appendix 45-Five MER question as part of data collection protocol for 2024

Appendix 46-CRDC Horizon Scholars email request

Appendix 47-Table of milestones outputs and outcomes for period June - November 2024

Appendix 48-plots of yield and CWUI on effective rainfall or crop water use

Appendix 49. Rainfed cotton yield on row spacing