Making Every Drop Count

How the Irrigated Cotton Industry in Australia can adapt to evolving climate challenges and better manage water as a limited resource

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Executive Summary

Water is the single biggest constraint on irrigated cotton production in Australia, and that constraint is tightening. Climate variability is increasing in both magnitude and unpredictability, while policy-driven water recovery continues to reduce on-farm allocation. Growers face a two-directional squeeze, and the businesses that adapt fastest will be the ones that remain profitable through it.

This report argues that semi-irrigated cotton is the adaptation. Not a reduced-intensity fallback triggered by water scarcity, but a deliberate farming system, built on rain-grown principles and scaled up or down against available water. Treated this way, low or no allocation years become a known and permanent feature of the system to be planned for, not an exception managed after the fact.

This research set out to examine how resilient farming systems mitigate climatic uncertainty; identify the management parameters that determine success in semi-irrigated cotton; evaluate how policy shapes the value of water and the incentive to use it efficiently; assess the barriers, risk attitudes and planning behaviours that influence adoption; and develop a practical framework growers and advisors can use to improve the productivity, profitability and consistency of these systems.

Findings are drawn from literature, eighteen months of conversations with growers, researchers and agronomists across four continents and a targeted survey of Australian growers, agronomists and researchers across the major cotton valleys. That evidence base sits behind three chapters.

Knowledge sets out five interacting levers of water use efficiency, plant management, farming systems, technology and data, policy, and people, none of which functions in isolation.

Process turns that knowledge into a five-stage decision cycle: Plan, Monitor, Adapt, Evaluate, Learn, that gives structure to decisions carrying different levels of operational weight.

Application brings both knowledge and process together against the seasonal question every irrigated grower ultimately faces, how much area to commit under a given allocation.

Tested against agronomic and economic analysis, no single allocation strategy wins every season. The report finds a hybrid model, committing most confirmed water to a fully irrigated priority area, with a smaller deficit-irrigated area alongside it offers the strongest balance of contained downside and retained upside, and positions a business to respond as the season unfolds rather than simply contract.

The recommendations that follow are directed at growers, advisors and industry: manage the crop to the water available, treat area commitment as a strategic decision rather than a default, build the confidence to act on monitoring and data, and stay engaged with the policy settings that determine the value of every efficiency gain made on farm. Together, they reflect a single shift in mindset, from managing semi-irrigated cotton as a response to conditions, to designing it as a system built for them.

Keywords: Cotton, water use efficiency, climate, decision making, farming systems

Table of Contents

Foreword

I fell into the cotton industry by chance. As a fresh-faced 18-year-old, I took a bug-checking job in Moree, having never seen a cotton plant. By the end of my first week, I was hooked. Nearly 14 years on, I'm still in Moree, working as an agronomist.

My Nuffield journey started long before I applied, as a genuine curiosity I couldn't let go of. The 2018/19 drought hit our region as a 1-in-100-year event. I spent those years driving around fallowed, hilled irrigation fields, talking to growers with no real way out short of a flood in the catchment. A boom-bust cycle, with volatile profitability on a fixed irrigation asset, presents real challenges for growers, businesses, and the communities they depend on. I kept thinking, we have to find a better way.

Australia is, in broadacre cropping terms, land rich and water poor. Water is the single biggest limiting resource across much of our production area. The industry has made incredible efficiency gains, where cotton growers now use around half the water to produce a bale compared with 30 years ago. Arguably, we face our biggest challenge yet: a two-directional squeeze from climate change and water recovery through policy.

I believe adaptation will be critical to the long-term profitability of irrigated cotton in Australia. Rethinking how we use water in lower-availability seasons to capture upside will be pivotal. Semi-irrigated cotton deserves to be understood on its own terms: not a lesser, scarcity-driven version of irrigated cotton, but a deliberate system, scaling up or down with the water available.

My aim in writing this report was to bring existing work together into a farming systems approach grounded in science, so growers, agronomists, and researchers alike could understand the potential fit for semi-irrigated cotton. Having the knowledge is one thing, I wanted to understand what processes are needed to make good decisions under constraint. That question shaped the seasonal decision matrix at the heart of this report, a tool to help growers make informed decisions around rotations and configurations, rather than defaulting to the known.

As a 2025 Australian Nuffield Scholar, I set out to test these ideas across the globe, seeking growers, researchers, and industry leaders working on the same challenge. It started as a physiology- and systems-based project and ended under a people and decision-making lens.

Early in my scholarship, I received an email reminding all Nuffield Scholars that, in the words of John Cyster, former UK Nuffield Chair, we must be penetrating in our analysis, forthright in our reporting, courageous in our practices, provocative in our advocacy, and adventurous in our forecasts. I took that to heart, perhaps too much so, given my first draft ran to 30,000 words. This has been a labour of love, cotton and Nuffield have a way of getting under your skin. I hope this research prompts a deeper look into your operation and the potential for semi-irrigated cotton to lift the profitability of your irrigated asset.

The table below sets out my Nuffield travel itinerary, followed by the key visits and contacts referred to throughout this report.

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
Nuffield National Conference **2nd- 6th September 2024**	Launceston, TAS Australia	Rose Roche- CSIRO Su McCluskey- Special Representative for Australian Agriculture Scholar Presentations Stefan Vogel- GM RaboResearch, Rabobank Regional Farm tour
Australian Focus Program **3rd- 7th March 2025**	DAFF Canberra, ACT Australia	Mel Brown, Laura Smith- Future Drought Fund Su McCluskey- Special Representative for Australian Agriculture Fiona Simpson- Vice Chair World Farmers Organisation Chris Parker- CEO Cattle Australia Catherine Marriot- 2024 Nuffield Scholar David Shearer- Australian Centre for International Agricultural Research Katie McRobert- Executive Director, Australian Farm Institute David Jochinke- Chair National Farmers Federation (NFF) CSIRO Black Mountain Site visit and Research tour
4th March 2025	Canberra, ACT Australia	ABARES Outlook Conference Driving Agricultures productivity and sustainable success
Contemporary Scholars Conference **7th- 16th March 2025**	Auckland, New Zealand	Professional Development workshops and scholar briefings Andrew Watene, KPMG Agribusiness- NZ and Global Agribusiness Vangelis Vitalis- NZ Chief Trade Negotiator Campell Parker, Tim Gibson- Dairy NZ Horticulture Field Trips- Cronin Road Research Farm, Balle Brothers, Punchbowl

Global Focus Program **18th- 22nd May 2025**	Singapore	Edible Garden City Khoon Goh- Head of ASIA Research, Mara Chiorean- ED, Sustainable Finance International, ANZ Bank Pasir Panjang Wholesale Centre, Redhill Market National University of Singapore
Global Focus Program **22nd- 26th May 2025**	Qatar	Baladna Food Industries Widam Food Qatar Shane Flanagan- Australian Ambassador to Qatar, Embassy Agrioco Agricultural Development
Global Focus Program **26th– 30th May 2025**	Belgium	Ksenija Simivic- Copa- Cogeca Robin Manning- British Agriculture Bureau (BAB) Johannes van den Bossche, Martin van Driel, European Commission, Agriculture & Rural Development Ghent University, Proeftuin Labs, Experimental Farm tour Tony Descamps- Flax Farm Tour Jeroen Dejonckheere- Dairy Farm Tour Bert Defruyt- Broadacre Cropping Farm Tour Sophie Marchal- Belgium Blue Farm Tour
Global Focus Program **30th– 7th June 2025**	France	Montauban Local Producers Market Lionel Lauture- farm tour Cadralbret SCA: Rougeline brand, Glasshouse, biogas, marketing Blonde d’aquitaine beef cattle breeding Kiko Hazelnut Rungis Market AGPB meeting- Wheat production in France OECD- Trade at the EU level CNE- National Center for Livestock and Animal Health
Global Focus Program **7th- 13th June 2025**	Ireland	Wicklow Mountains National Park John Clake, Ian Fox, Department of Agriculture, Food and Marine (DAFM)

		Seamus McMenamin- Bord Boa Brian Nicholson- Sheep and Biodiversity tour Graham Poole, Hughes Farming- vegetable grower and processor Eamonn Sheehan- Smart tech for Smarter Farming, farm tour and field day Kepak Clonee- abattoir tour Paul Crosson- Teagasc Grange, Beef Production Research Centre Silverhill Ducks Monaghan Mushrooms
Global Focus Program **13th- 26th June 2025** **14th August 2026**	Brazil	MAPA- Overview of Brazilian Agribusiness CNA- Brazilian Farming representation group EMBRAPA Cerrados- RDE in Brazil, research farm visits Australian Embassy Malunga- vegetable farm tour SLC Farm tour- cotton production, dryland and irrigated farming Ecocitris- organic essential oils Be8 Biofuel site tour Martins Agrobegocios- J2M group Teodora Lutekmeyer- Family farm tour, beef and broadacre cropping Michelle Birck- Juntos Coworking, leadership in Agribusiness Cotrijal- large cooperative Atitus Educacao- University research tour Eduardo Ferreira- Agronomist Bahia
USA Study Tour **Texas, USA** **4th- 18th August**	Texas A&M- College Station Dallas, Texas Lubbock, Texas	Dr, Giovanni Piccinn- Director, Texas Water Research Institute Dr. Ben McKnight Cotton Extension Agronomist, trial walks Dr. Wayne Smith- Cotton Breeder Dr. David Baltensperger- Head of Agronomy Lori Nemic- Private Consultant/ Agronomist Texas A&M AgriLife Water Symposium Paxton Payton- BASF

		James Mahan- Goanna Ag Deltapine Bayer Processing Plant Dr. Ken Lege, Rebekah Ortiz- Putejovsky- Cotton Extension Specialist Dr. Katie Lewis (Texas A&M AgriLife) Dr. Irish Lorraine B. Pabuayon, cotton physiologist at Texas Tech University
	San Saba, Texas	US Scholar Kristen Millican- Millican Pecans
USA Study Tour **Mississippi, USA** **18th- 24th August**	Mississippi State University (MSU)	Dr. Brian Pierlisi- State Cotton Extension Specialist for Mississippi Dr. Jason Barrett, Dr. Dave Spencer- Mississippi Water Resources Institute Dr. Whitney Crow- Extension Cotton Entomologist at MSU Dr. Alex Thomsson, Dr. Wes Lowe- Agricultural Autonomy Institute
	Delta Research & Extension Centre	Dr. Nicolas E. Quintana Ashwell- Agricultural Economist at the National Centre for Alluvial Aquifer Research Dr. Drew Gholson- meetings and farm tours Chris Delhom- Stoneville Gin Lab Jeremy Jack- Silent Shade Planting Company Jay Mahaffey- Scott Learning Centre, Bayer Sledge Taylor- grower farm tour
USA Study Tour **Tennessee, USA** **24th- 27th August**	Jackson TN. University of Tennessee (UT)	Kelly and Matt Griggs- Griggs Farms LLC Farm tour Dr. Tyson Raper- UT cotton extension Agronomist Dr, Avar Shekoofa- Crop physiologist UT
USA Study Tour **24th- 27th August**	Missouri Leighton, Alabama Tifton, Georgia	Dr, Brad Wilson, Cotton extension specialist Tripp Cooke- Agronomic Consultant Helena Agri Dr. John Schnider, University of Georgia, Cotton Physiologist
18th March 2026	Spring Ridge, NSW Australia	Grower of the Year Field Day Merrilong Agricultural Co.

25th March 2026	Moree, NSW Australia	Mick Humphries- Chesney Farming
2nd-3rd June 2026	Coogee, NSW Australia	Cotton Australia General Meeting CRDC Research Priorities Meeting & update
16th- 17th June 2026	Narrabri, NSW Australia	Crop Consultants Australia Seminar
1st July	Moree, NSW Australia	Zara Lowien- CEO National Irrigators Council

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Firstly, a sincere thank you to Nuffield Australia for selecting me as scholar. This opportunity has altered the trajectory of my life and afforded me incredible personal and professional opportunities. The belief and support of the broader Nuffield community, in Australia and globally, is second to none. Thank you for welcoming me into your homes and businesses, I cannot wait to return the favour. A big thank you also to the Nuffield Team, especially Tessa Dimond, for being a great support throughout.

Secondly, thank you to Cotton Australia and the Cotton Research and Development Corporation (CRDC) for investing in me. I am extremely grateful to be the first industry-based scholar for the Cotton Industry and look forward to extending my research and giving back in the years to come.

To the people I met, visited and interviewed during my Nuffield travels, thank you for the conversations that have shaped this report. A special thank you to Mick Bange for facilitating my USA study tour, a career highlight to date. I was fortunate to spend time with researchers and agronomists who went above and beyond, I look forward to having you out in the field here in Australia soon.

Thank you to the country hosts on our Global Focus Program (GFP) for the effort that goes into planning each visit. To the exceptional scholars I shared my GFP with; Thanh Truong, Tom Polkinghorne, Nikki Gilder, Jenna Sarich and Jose Luchsinger, you genuinely inspire me, and I am a better person for knowing you. I look forward to many years of friendship.

To the Poole Ag team, thank you for the sacrifices you made for my extended time away. I am appreciative of your encouragement to pursue my passions and look forward to the opportunity to grow together in the years to come.

To my friends and family. I know everyone says they are so lucky etc. but I am genuinely so fortunate to have the support network I do. A career in cotton has at times kept me away from home more than I'd like, but I am so grateful for your unwavering support. Your friendship has shaped my successes, both personal and professional and I am grateful you have embraced and invested in my Nuffield as if it was your own.

And to Connor. We have both grown so much since meeting at the start of this journey. I knew Nuffield would change my life, but falling in love with a salmon farmer from Tassie wasn't what I had in mind. I will be forever grateful our paths crossed.

Nine countries, over 30 flights, hundreds of farm visits, well over 10,000km driven; Nuffield has been one hell of a ride, and I wouldn't change a thing! This truly has been a once in a lifetime opportunity that has instilled a love of travel and learning that will stay with me forever.

Figure 1: GFP 4 Team- Thanh Truong, Tom Polkinghorne, Nikki Gilder, Jenna Sarich and Jose Luchsinger (Source: Author).

AI tools (ChatGPT, Claude) were used throughout the preparation of this report, including for the design and formatting of figures 2 and 12–16, transcription of interviews and meetings, and support in synthesising and organising ideas during the writing process. All data interpretation, analysis, and conclusions presented in this report are entirely the author's own work.

Abbreviations

ABARES	Australian Bureau of Agricultural and Resources Economics and Sciences
AI	Artificial Intelligence
APSIM	Agricultural Production Systems sIMulator
CA	Cotton Australia
CEO	Chief Executive Officer
CO_2	Carbon Dioxide
CRDC	Cotton Research and Development Corporation
CSD	Cotton Seed Distributors
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTF	Controlled Traffic Farming
CTS	Canopy temperature sensors
EM	Electromagnetic
ESG	Environmental, Social and Governance
EU	European Union
FAO	Food and Agriculture Organisation
Ha	Hectare
MDBA	Murray Darling Basin Authority
MDBP	Murray Darling Basin Plan
ML	Megalitre
NAWF	Nodes above white flower
NCAAR	National Center for Alluvial Aquifer Research
NDVI	Normalised Difference Vegetation Index
NIC	National Irrigators Council
OECD	Organisation for Economic Co-operation and Development
PAWC	Plant available water capacity
PCD	Plant Cell Density
PGR	Plant growth regulators
UAV	Unmanned Aerial Vehicle
US	United States
USDA	United States Department of Agriculture
VPD	Vapour pressure deficit
WHC	Water holding capacity

WUE Water Use Efficiency

Key terms

Adaptive management

The ongoing systematic process of learning, refining and reorganizing management practices

Fallow Efficiency

The proportion of rainfall that fell during the fallow period that is stored and available to the following crop, expressed as a percentage.

Water Holding Capacity

Water holding capacity (WHC) is the amount of water a soil can retain in the root zone for plant use, the water held between field capacity and permanent wilting point, typically expressed in mm per unit depth of soil.

Water Use Efficiency

WUE is a measure of agricultural output produced per unit of water used, typically expressed as yield per megalitre applied or consumed. WUE is commonly calculated a few different ways depending on what's being measured:

- Irrigation WUE: yield per ML of irrigation water applied
- Crop WUE: yield per ML of total water used by the crop (irrigation + rainfall + stored soil water)
- Gross production WUE: total lint yield per ML across the whole water budget, often the figure used for benchmarking across seasons or systems

Objectives

This research investigates how semi-irrigated cotton systems can be optimised to improve water use efficiency (WUE), productivity and profitability in water-limited environments. As climatic variability increases and water resources become more constrained, improving system resilience and water productivity will be critical to the long-term sustainability of irrigated cotton production in Australia.

The key objectives were to:

- Examine the role of resilient farming systems in mitigating climatic uncertainty and resource scarcity
- Identify the key management parameters that influence the success of semi-irrigated cotton
- Evaluate the role policy plays in the value of water and its influence on WUE
- Assess barriers to adoption, attitude to risk and the role planning plays in adaptive farm management
- Develop an accessible framework to support growers and consultants in maximising the productivity, profitability and consistency of semi-irrigated cotton systems

Introduction

The Australian Cotton Industry and its place in a global context

Cotton is a globally traded commodity. It is embedded in a supply chain linking production systems with textile manufacturing and consumer markets worldwide. Within this system, Australia occupies a unique position. While contributing only a small proportion of global cotton production, it is consistently one of the world's largest exporters, supplying high-quality fibre into international markets (Australian Cotton Shippers Association, 2026; USDA, 2025). This export-focused industry operates in a highly competitive and volatile global environment, where profitability is influenced by international supply and demand, trade dynamics and shifting consumer expectations. Australia's competitive advantage lies in its ability to produce some of the highest yielding and most water-efficient cotton globally, underpinned by sustained investment in research, rapid adoption of technology and a commitment to sustainability and traceability (ICAC, 2025; ABARES, 2026). As global pressures on water resources, climate variability and market access intensify, understanding Australia's role within this broader industry is critical to identifying pathways that enhance resilience, productivity and long-term viability.

The role of farm resilience in climatic uncertainty

Climate change is driving both gradual shifts in climatic conditions and an increase in the frequency and intensity of extreme events. In Australia, this is particularly evident through more frequent droughts, altered rainfall patterns and rising temperatures, which directly influence water availability and crop performance (Henry & Howlett, 2021). Climate variability has long been a defining feature of Australian agriculture; however, the magnitude and unpredictability are increasing, presenting new challenges for farm management and decision-making (Hughes, Galeano, & Hatfield-Dodds, 2019).

Resilient farm businesses are characterised as those with the capacity to prepare for, absorb, recover from and adapt to adverse events, highlighting that resilience is both a short-term and long-term capability (Sauer, Mennig, Chancellor, & Anton, 2024; ABARES, 2023). Farm resilience is not determined by a single factor but rather the interaction between multiple attributes, including:

- Financial capacity and risk management
- Adaptive management practices
- Efficient resource use
- System diversity and flexibility
- The utilisation of information and technology
- The influence of broader policy and investment settings.

These attributes are interdependent and critical to managing production risk and economic exposure on farms. For the purposes of this report, farm resilience is treated as the umbrella outcome that cotton growers are managing for. The five levers of water use efficiency represent the practical, decision-level mechanisms through which that resilience is built and maintained on farm and will be outlined in Chapter 1.

Variable water availability, combined with the capital-intensive nature of irrigated cotton production, amplifies the financial consequences of inefficient production (Henry & Howlett, 2021). The primary challenge posed by climate change for cotton production is not only a shift in average climatic conditions, but an increase in variability and uncertainty. This reduces the predictability of production and alters physiological responses: heat stress above approximately 35°C limits the assimilates available for fruit growth, causing square and boll shedding and reduced seed set, and these yield and quality impacts are significantly exaggerated when water stress occurs concurrently (Bange & Brodrick, 2018). As a result, traditional approaches to management become less reliable.

Ultimately a shift towards adaptive, responsive and data-informed management systems is key to improving WUE and system resilience to sustain cotton production in water-limited environments.

The role of policy on the value of water

Policy operates one step removed from the farm, shaping the value of water before it reaches the grower rather than how efficiently it is used once it arrives. Allocation frameworks, water trading and infrastructure investment determine how secure, abundant and costly water is. It is this value, more than any on-farm factor, that drives the incentive to invest in the efficiency measures explored throughout this report. Where policy creates clear price signals and secure entitlements, growers are incentivised to use water efficiently; where that signal is weak, the same incentive does not hold, regardless of the technology or management available on farm. This relationship between policy, water value and on-farm WUE is explored in Chapter 1.4.

Semi-irrigated cotton systems

One of the biggest challenges when discussing semi-irrigated cotton is settling on a definition. Total water application alone is not a sound indicator, as a crop receiving a seemingly modest volume may still be meeting its full requirement, while a crop receiving a large volume may still be in deficit. Nor is irrigation system a reliable proxy, as the same infrastructure can be used to apply water at full requirement or well below it. For the purposes of this report, semi-irrigated cotton is defined as a crop that is deliberately watered below the requirement for maximum production. In these systems, production relies on a combination of stored soil moisture, opportunistic rainfall and limited irrigation, bridging the gap between dryland or rainfed systems and strictly irrigated crops.

This deficit can be delivered through a range of infrastructure, each with different implications for the water use efficiency levers explored later in this report. Overhead irrigation systems such as pivots and laterals have traditionally suited semi-irrigated cotton particularly well, as they allow lower volumes per hectare to be applied accurately across multiple passes, making a sustained deficit more readily achievable than under systems designed around larger, less frequent applications. In recent years there has also been some uptake of drip tape irrigation. Despite this, the industry remains dominated by furrow irrigation under grade, fed through channels with siphons. Within furrow systems, there has been significant uptake of bankless, or siphon-less, irrigation, where water is dropped into terraced bays and run through furrowed fields. This shift has been driven predominantly by labour cost savings, though it is also delivering benefits elsewhere in the farming system, including documented improved water use efficiency.

Industry research

A targeted survey of Australian cotton growers, advisors and industry professionals complemented the field research, case studies and literature review found in this report. It was used to capture practical insight into the constraints, current management strategies and opportunities for improving WUE in semi-irrigated systems. Responses grounded the report's themes in commercial reality alongside the scientific and field evidence.

The survey was distributed to three respondent groups: growers, agronomists, and researchers and industry/extension personnel, from across the major cotton-growing valleys including the Gwydir, Upper and Lower Namoi, Macquarie, Murrumbidgee, Macintyre and Darling Downs. Several consistent themes emerged, and are summarised below, with full methodology and supporting data available in Appendix 1.2.

Across all groups, the cost and scarcity of water was the dominant driver of WUE, followed by infrastructure condition, system losses and irrigation timing. Growers and agronomists emphasised minimising transmission and storage losses, while researchers flagged over-irrigation in good-water seasons as an under-addressed inefficiency, with WUE outcomes seen as governed as much by the irrigator's skill and decision-making as by infrastructure or technology. On benchmarking, most growers do not currently track WUE but want to, agronomists do so more often, and researchers supported the practice in principle while cautioning that bales per megalitre can be misleading, as gains often reflect agronomy or season rather than water management alone.

Single skip or 60-inch configuration (66% green area) was the preferred row arrangement across all groups, balancing plant population against root access and harvest compatibility, with double skip better suited to dryland systems given its lower achievable population. For row configuration summary please see appendix 1.1. Water budgets converged on 3-6 ML/ha, typically a water-up event plus one to three in-crop irrigations, workable only when supported by adequate starting soil moisture and reasonable in-crop rainfall. The key triggers identified for planting a semi-irrigated crop were a full starting soil moisture profile, a favourable rainfall outlook, standing stubble, constrained or costly water allocation, and a supportive price. The key challenges were rainfall-driven variability, unreliable medium-range forecasting, grower risk appetite and debt exposure. A minority of growers would not consider semi-irrigated cotton at all, citing the financial risk relative to simply trading water on the temporary market.

Plant growth regulator (PGR) use to manage canopy architecture under limited water was near-universal among growers and agronomists. One researcher cautioned against this as a true water-saving strategy, arguing that water use is fundamentally a function of leaf area, temperature and season length. It was noted that PGRs should respond to plant indicators rather than follow a fixed seasonal program.

Overall, responses revealed a divide in how semi-irrigated cotton is framed: for some growers, a risk-mitigation and cost-saving response to reduced allocation; for others, including most researchers and agronomists, a deliberate system design choice for operations with more water entitlement than irrigable land. This distinction has shaped the structure and direction of the research that follows. A full summary of findings is provided in Appendix 1.2.

Project Scope

This report explores the opportunity and positioning of semi-irrigated cotton in building resilient, profitable farming businesses. The intent is not to frame semi-irrigation as a reduced-intensity fallback, but as a deliberate strategy for scaling up production, capturing opportunity when conditions allow, and preparing for low or no allocation years as a known and recurring feature of the system not an exception to plan around after the fact.

For some growers, operating in this space is already business as usual. For most, however, semi-irrigated and water-constrained cotton production will need to become a core part of strategy moving forward, not by choice alone, but out of necessity. The foundation for this approach should be the same set of agronomic principles that underpin rain-grown cotton, with irrigation layered on top to reduce risk and improve the consistency of results.

Practically, this report asks what that looks like on farm: what can be implemented to reduce risk and increase profitability under variable allocation. In low or no water years, this means maximising the water-holding capacity of soils, prioritising crop rotation with the same discipline applied in broadacre systems and increasing planting opportunity where conditions allow. Rotation is not without its complications. This can mean directing water to a crop with a lower return per megalitre (ML) in the short term, but when viewed across the full rotational timeframe (e.g. five years), the reduction in inoculum load and improvement in soil function lifts profitability overall.

No two farming systems look the same, and the specific mix of constraints will vary from business to business. What is consistent, however, are the underlying challenges and opportunities. Being proactive rather than reactive creates more room to adapt and manage these variables earlier, and more effectively. This report does not attempt to prescribe a single model for semi-irrigated cotton. There are many ways to approach this system, and the principles set out here need to be understood and applied against the specific variables of each business. The intent is to put in place guide rails: a practical framework that helps growers materialise upside and manage downside risk, with the aim of improving the reliability and repeatability of outcomes, the foundation for both adoption and long-term profitability.

This report is structured around three chapters. *Knowledge* lays the foundation, framed as the five levers of water use efficiency. *Process* turns that knowledge into action, through a decision cycle that recognises decisions carry different operational weight and value. *Application* brings the two together, applying them to the central seasonal question: how much area to commit under a given water allocation, explored through economic and agronomic analysis of allocation options. Together, Knowledge, Process, and Application form the practical framework this report sets out to deliver.

Chapter 1- The five levers of water use efficiency

This chapter provides the foundation for decision-making that maximises productivity and profitability under water-limited conditions. It introduces five levers that drive water use efficiency including plant management, farming systems, technology and data, policy, and people. Together they determine how effectively water is converted into yield and return. Understanding how these levers interact, and where growers and advisors can intervene to greatest effect, is essential groundwork for the decision framework applied in the proceeding chapters.

Figure 2: The five levers of water use. Each lever represents a distinct knowledge area that informs every stage of the decision cycle (Source: author).

1.1 Plant Management

Plant management is a critical lever in semi-irrigated cotton, governing the crop's physiological capacity to capture, use and convert water into yield. While water availability sets the upper limit on production, how the plant responds to deficit and stress, and how growers manage that response, drives the variation in performance achieved. Improving WUE is therefore not solely a function of water availability, but of how effectively management aligns crop physiology with the constraints of the production environment.

At the physiological core of this lever is stomatal regulation. Stomata balance CO_2 uptake for photosynthesis against water loss through transpiration; under declining soil moisture or high vapour pressure deficit, stomata close to conserve water, but prolonged closure restricts photosynthesis, biomass accumulation and ultimately yield (Farquhar & Sharkey, 1982; Lawson & Blatt, 2014). This carbon-water trade-off is most consequential during flowering and early boll development, when demand from establishing fruit is high and early bolls are most vulnerable to carbohydrate shortfall (Baker & Baker, 2010).

Root architecture and canopy management are the two practical levers growers can use to manage that trade-off. A well-developed root system extends the crop's access to stored and subsoil moisture, buffering short-term supply gaps and reducing reliance on frequent irrigation (Bange & Constable, 2015; Lynch, 2013). Because early root development shapes water access for the rest of the season, a light deficit at establishment, enough to encourage roots to drive root growth, but not so severe it restricts their growth, builds resilience for the more sensitive reproductive stages ahead. This underpins deficit irrigation as a planned strategy rather than a reactive response: prioritising water to the periods of greatest physiological sensitivity, informed by soil moisture monitoring, rather than applying it reactively to visible stress.

Canopy management works in the same direction. Cotton's indeterminate growth habit means vegetative growth can continue alongside fruiting, and excess canopy increases transpirational demand without contributing to yield. PGRs, principally Mepiquat chloride, are used to moderate vegetative growth and redirect assimilate toward reproductive development, improving light penetration and fruit retention where water is limited (Bednarz, Nichols, & Brown, 2006; Nichols, Snipes, & Jones, 2003). The objective is not growth suppression for its own sake but aligning canopy function with seasonal yield potential and available water. Over-application under moisture stress can compound growth suppression and reduce boll fill (Pettigrew, 2004), so PGR strategy needs to sit within the broader irrigation plan rather than stand alone.

Because yield is most sensitive to stress from squaring through peak bloom, with water depletion at flowering associated with yield losses of up to 39% (Wang et al., 2017). These root and canopy levers matter most in how they're sequenced across the season, which is ultimately a water budgeting exercise, allocating limited water to the periods of greatest physiological payoff.

Varietal selection offers a smaller, complementary lever: traits such as determinacy, boll accumulation efficiency, fibre quality stability and transpiration efficiency influence how well a cultivar's water demand aligns with constrained supply (Bange & Constable, 2015).

Extended discussion of these physiological and management principles is provided in Appendix 2.1.

Plant Management in Practise: Global insights

"We should be utilising plant-based indicators alongside our traditional approaches to irrigation scheduling."

- Dr. John Snider, Crop and Soil Sciences,
  Tifton, University of Georgia

Meeting Dr John Snider at the University of Georgia's Tifton campus and touring the irrigation-by-physiology trials at the C.M. Stripling Irrigation Research Park, was one of the more technically grounded stops on my study tour. The trials characterise how cotton physiologically responds to yield-limiting stress and test management strategies, including PGR regimes, that improve WUE under those conditions. Snider's group has shown aggressive Mepiquat chloride management ahead of drought reduces the crop's sensitivity to water stress during peak demand, but the same strategy incurs a yield penalty if the crop is no longer water-limited later in the season (Lee, Snider, Roberts, & Hand, 2023). It's a conditional bet, not a blanket rule, weighed against the seasonal outlook much like the area-commitment decisions at the heart of this report.

What struck me was the shift in reference point. Most irrigation decisions are still made off soil moisture probes and fixed scheduling triggers, proxies for the plant's environment rather than its actual response to stress. Snider's research treats the plant itself as the more accurate integrator of that stress, namely growth rate and nodes above white flower.

This is directly relevant to Australian semi-irrigated systems, where water stress is shaped by timing, sequencing and seasonal variability rather than a controlled deficit. Physiological indicators of stress, and management tuned to them, are arguably more valuable in this kind of variable system than in a fully irrigated one where the plant's environment is already tightly managed.

Figure 3: In the field with John at the C.M. Stripling Irrigation Research Park (Source: Author).

"Plant growth regulators are a fundamental tool to drive yield"

- Jay Mahaffey, Learning Centre Manager and Science Fellow at Bayer, Scott, Mississippi, USA

A US tour wouldn't be complete without the Bayer Learning Centre in Scott, Mississippi, where Jay Mahaffey walked the Mississippi State University (MSU) team and I through long-term trials on how PGR use drives yield. The main mechanism was by reallocating the plant's energy from vegetative development to reproductive growth. For cotton's indeterminate growth habit, that reallocation is central to unlocking yield potential already built into existing varieties.

The trial data made the case in specific terms: PGR use increased fruit retention, total boll number, and the proportion of higher-yielding five-locule bolls. In the Learning Centre's 2024 positional mapping trial across six varieties, untreated plots produced axillary ("back fruiting") fruit equivalent to around 1.57kg lint/ha, while aggressively managed plots produced around 25.78kg/ha from those same positions (Bayer Crop Science, 2025).

The relevance to Australian semi-irrigated systems is direct. Where water is the binding constraint on area and yield, PGR strategy is one of the few levers that can lift yield potential without requiring more water. Reallocating energy toward reproductive positions that convert efficiently, rather than into vegetative growth that doesn't. Yield potential isn't fixed by variety alone; it's shaped by how the plant's energy is partitioned once it's growing.

Figure 4: Tour at the Bayer, Scott Learning Centre with the MSU team, followed by dinner at Greenville Mississippi famous steakhouse Does. Pictured with Drew Golson and Chris Delhom from the Delta Experiment Station, Stoneville (Source: Author).

Collectively, these physiological and management dimensions demonstrate that WUE in semi-irrigated cotton systems is not determined by water availability alone, but by how effectively that water interacts with crop physiology across the season. From stomatal regulation and canopy architecture through to root development, stress timing and varietal selection, each area represents a point of leverage where informed management decisions can shape crop performance under constraint. Rather than treating water deficit as an unavoidable limitation to be endured, this understanding positions plant management as an active lever for aligning crop development with available water, capturing productivity opportunities as they arise and building resilience against the variability inherent to semi-irrigated production.

1.2 Systems based approach

Where plant management focuses on how efficiently the crop uses available water, farming systems management focuses on how effectively that water is captured, stored and delivered to it. System design shapes not only water availability, but risk exposure, operational flexibility and the consistency with which production opportunities convert into profitable outcomes. These decisions operate across three dimensions, strategic, tactical and temporal, each shaping the others and collectively determining how well a system responds to variability. This section examines how decisions across each dimension interact to shape overall system performance.

Strategic decisions establish the framework within which a season is run. Farm performance is shaped by the interaction of multiple system components and choices over time, not by isolated season-to-season decisions (Thyer, 2025). Two choices matter most: crop sequencing and risk positioning. Rotational design goes beyond the performance of any single crop, it shapes soil structure, water storage capacity, disease pressure and the labour and machinery demands of the wider system. Diverse rotations are associated with improved resilience under climatic variability (Lin, 2011). In semi-irrigated systems, where stored soil moisture is a critical production asset, the preceding crop strongly influences both the volume and accessibility of water available to the next. Risk positioning is the second lever: matching system intensity (crop area, input investment, production ambition) to realistic water availability and risk tolerance for the season (Welsh, Taschetto, & Quinn, 2022). Growers who resist the temptation to overcommit, preserve the financial and operational headroom to act aggressively when conditions favour it.

Tactical decisions convert that strategic framework into in-season performance. Controlled traffic farming (CTF) should be prioritised to confine machinery to permanent lanes, protecting soil structure and infiltration capacity within the crop zone and reducing the compaction losses that would otherwise diminish stored water and crop establishment (Tullberg, Yule, & McGarry, 2007). Crop configuration including row spacing, plant population and skip-row arrangements can also be utilised, trading yield ceiling against water demand: solid plant maximises yield potential but carries the highest water requirement, while skip-row configurations reduce crop intensity to better match constrained supply. Reduced tillage, stubble retention and cover cropping conserve that supply further, moderating evaporative losses and improving infiltration between and within seasons. Though cover crop water use during fallow periods must be managed carefully to avoid depleting the moisture reserve intended for the following crop. Sowing date is the final major lever: later sowing shifts peak water demand into cooler, lower evaporative-demand conditions, improving the efficiency with which limited water converts to yield (Anwar, Wang, Liu, & Waters, 2020), while operational readiness, namely the ability to act quickly on a sowing or irrigation opportunity is what allows growers to convert these tactical choices into results across a season that rarely unfolds as planned.

Strategic and tactical decisions compound over time rather than acting in isolation. Practices that build soil structure and water holding capacity may deliver modest returns in any single season but accumulate significantly across seasons of variable water availability. Conservative risk positioning in constrained years preserves the headroom to act more aggressively when conditions improve. What distinguishes consistently high-performing systems is less any single decision than the capacity for adaptive management; learning from outcomes, adjusting strategy in response to new information, and continually refining the fit between system design and the production environment. In semi-irrigated cotton, where seasons of abundance and constraint vary, this longer-term view is the foundation for converting variability into a durable competitive advantage rather than a recurring vulnerability.

What does that mean in practice?

- *Plant into retained stubble under reduced tillage*
  Stubble retention and reduced tillage protects soil structure, reduces evaporative loss and improves fallow water capture.
- *Build and protect fallow moisture*
  Planting into stored soil moisture, not watering up, shapes establishment, root development and the water available through flowering and boll fill.
- *Match configuration and planting date to available water*
  Row spacing and plant population are the most accessible levers for matching crop water demand to availability, while sowing date shifts peak demand into cooler, lower evaporative-demand conditions.
- *Invest in soil health and long-term nutrition*
  Treating soil as a productive asset, not just a growing medium, sustains system function under constraint.
- *Prioritise timeliness of operations*
  Narrow sowing and irrigation windows make operational readiness a system design requirement, not simply good practice.
- *Critically analyse and benchmark performance*
  Understanding what drives performance, internally or through services such as AgriPath, is what separates systems that improve over time from those that don't (Agripath Pty. Ltd. , 2024).

Extended discussion of these system-design principles is provided in Appendix 2.2.

Farming Systems in Practise: Global insights

“Upside potential is often lost in poor setup”

- Mick Humphries, Cotton Grower, Moree, NSW Australia

In semi-irrigated systems, there is inherently greater capacity to capitalise on rainfall than in fully irrigated production. Yet in Australia, semi-irrigated cotton is often grown within traditional hilled irrigated infrastructure rather than systems designed around rain-grown principles, a production environment that actively limits the very water capture potential that makes semi-irrigated cotton viable in the first place. The underperformance that follows should not be surprising.

I have been fortunate to work with Mick for a number of years, and this concept has been a recurring thread throughout. We always come back to the same fundamental: ***the decision framework for semi-irrigated cotton should build outward from dryland thinking, not depart from it.*** The same principles that underpin success in rain-grown systems translate directly, with irrigation providing reliability rather than replacing the system entirely. Soil function, surface cover, fallow efficiency and operational readiness matter more under constraint, not less.

This was reinforced through global travel. The specific constraint changes with geography, in the Mississippi Delta, the critical system lever is drainage rather than water capture, but the underlying principle remains constant: identify what limits system performance, and design around it. As water availability becomes more variable, the focus must shift from crop performance to system performance. Maximising return/ML, not yield (bales/ha), is the metric that will define success in semi-irrigated cotton systems moving forward.

Figure 5: Assessing plant growth and PGR requirements in the field with Mick Humphries (Source: Author).

"We started exploring no-till to reduce erosion and over time have transitioned to a wholistic regenerative approach to farming which is centred around reduced tillage and cover cropping.

The soil is softer, we have increased microbiology and improved aggregation which in turn has increased infiltration, reduced runoff and improved WUE."

- Sledge Taylor, Cotton Grower, Como, Mississippi USA

Walking paddocks with Sledge Taylor on his farm in Como, Mississippi, was one of the more memorable experiences of my study tour. The textural difference between his cover-cropped and non-cover-cropped fields was immediately tangible underfoot. His red loams were hard setting without residue retention, and as the season progressed, reduced infiltration translated directly into reduced yield. Sledge hadn't arrived at his regenerative approach through ideology, he had arrived at it through observation, on-farm data and a genuine understanding of soils as a productive asset.

The logistical insight he offered was as practical as it was simple. Cover cropping competes with harvest for time and attention, so Sledge flies his cover crop on immediately prior to harvest, removing the bottleneck entirely. His point was direct: if it isn't prioritised, it won't get done, an approach grounded equally in science and on-farm performance results.

The application for Australian semi-irrigated systems is genuine. Irrigated cereals rarely compete with cotton on return/ML, limiting their appeal as rotation options in water-limited systems. Cover cropping, whether established on residual moisture or sown opportunistically following rainfall, fits naturally into this gap, building soil function during fallow periods without competing directly with cotton for water allocation.

Soils, as Sledge's system demonstrates, are not a static medium but a productive asset that responds to management over time. In variable, water-limited environments, investing in that asset is sound agronomy, not idealism.

Figure 6: In the field with Sledge Taylor, discussing soil and crop health. (Source: Author)

Taken together, these strategic, tactical and adaptive principles show that WUE in semi-irrigated cotton comes not from any single decision, but from how well a system is designed to convert inherent variability into consistent, profitable outcomes. Strategic choices set the risk profile and resource base; tactical decisions determine how effectively that framework is executed within a season; adaptive management ensures the system keeps improving across seasons. Semi-irrigated cotton is not a compromise imposed by limited water, but a production system in its own right, whose performance depends on deliberate design choices made well before a season begins.

1.3 Digital Agriculture: The value of technology and data

Technological innovation has long underpinned agricultural progress, and its role is evolving from improving operational efficiency to enabling more informed, adaptive decision-making. Realised as a shift from precision agriculture toward digital and decision agriculture, where interconnected technologies and data systems support management decisions (Perrett, Heath, Laurie, & Darragh, 2017). In semi-irrigated cotton, this matters because water allocation decisions extend beyond operational precision into strategic resource allocation under uncertainty.

The value of technology can be considered across three functional roles:

- Monitoring, to improve visibility across the production system.
- Decision support, to convert information into action.
- Operational execution, to turn decisions into outcomes.

Understanding available water is fundamental to irrigation decision-making. Capacitance probes and telemetry platforms track water extraction through the soil profile, identifying emerging deficits before visible crop stress occurs and informing first-irrigation and post-rainfall timing decisions. Fixed-point tools remain only a snapshot, and their value depends on placement and an understanding of soil variability. Canopy temperature sensors address that gap directly, measuring crop water stress on the principle that stomatal closure under deficit reduces transpirational cooling and raises canopy temperature relative to ambient conditions. Fixed sensors are most common in Australian systems with UAV and thermal platforms emerging. Complementary technologies including EM surveys, weather stations and evapotranspiration tools, and satellite/NDVI imagery extend this visibility spatially and environmentally, sharpening the water budgeting picture that underpins irrigation planning.

Irrigation scheduling platforms integrate soil moisture, crop stress and evapotranspiration data with weather forecasting to align irrigation timing and volume with crop demand, replacing fixed scheduling intervals with a fuller picture of system performance. Commercial data platforms such as Goanna Ag are increasingly adopted across Australian cotton systems. But at a strategic level, the most effective decision support is often not a platform but a person. Agronomists, business advisors and benchmarking professionals translate data into strategic recommendations; helping growers weigh crop choice, input investment and production ambition against risk, capacity and long-term objectives. Predictive and retrospective analytics extend this further, forecasting yield potential under variable conditions and identifying recurring constraints across seasons. The consistent finding, though, is that good data and experienced counsel together convert information into sound decisions more reliably than either alone.

The value of monitoring and decision-support technologies is ultimately realised at the point of execution. Labour and operational capacity are persistent constraints in

Australian cotton systems, and during critical periods. Competing time-sensitive operations can limit how precisely and promptly growers can respond. Automation technologies, including remote pump start-stop systems, automated bay and gate control and telemetry-enabled irrigation management, address this directly by reducing reliance on manual intervention and extending the operational reach of the grower and advisor across multiple fields at once. Water delivery monitoring (dam and channel sensors, flow monitoring) supports more accurate water accounting and closes the loop between what is planned and what is applied. Ultimately, infrastructure design sets the ceiling on what these technologies can deliver: the best decision poorly executed still produces a suboptimal outcome, so investing in infrastructure that enables technology to function as designed is as much a productivity decision as the technology itself.

Extended discussion on specific technologies being employed and the role of data driven decisions is provided in Appendix 2.3.

Technology in Practise: Global insights

"Pulling out relevant data is easier than ever, interpretation is key"

- James Mahan & Paxton Payton
  Former United States Department of Agriculture (USDA)
  now Goanna Ag and BASF respectively

Two names synonymous with deficit irrigation in Texas are James Mahan and Paxton Payton. After long and successful careers at the USDA Cropping Systems Research Laboratory in Lubbock, both have transitioned into the private sector, roles that reflect a commitment to translating research into commercial practice. Their extensive collaboration with Australian irrigation and physiology researchers made them a priority visit on my study tour.

Time in the truck and walking fields was valuable, but it was sitting around the dinner table, chats over a strong coffee and working through field data that proved most instructive, both for this research and more broadly as an agronomist.

A central theme of those conversations was yield stabilisation in constrained environments. The insight that stayed with me was deceptively simple. Often it is not how much water a crop receives that determines the outcome, but when. Their rainfed research consistently showed planting date to be a stronger predictor of yield than total seasonal rainfall (Mahan & Payton, 2018). The implications for how we monitor, interpret and respond to in-season conditions are significant.

Growing water-limited cotton is entirely normalised in the Texas high plains, where decades of declining groundwater from the Ogallala Aquifer have forced producers to adapt their systems, their management and their thinking. Semi-irrigated cotton productivity in Australia, by contrast, is known for its volatility. It reflects systems and management approaches that were largely designed for fully irrigated production and are not well adapted to water-limited conditions. The tools exist. The gap is in interpretation. Knowing what the data means, when it matters and how to act on it. Modelling can help bridge that gap, improving our understanding of how to adapt management in response to rainfall timing and water availability across the season. That is the bridge James and Paxton have spent their careers building, and their message is both a challenge and an opportunity for Australian semi-irrigated cotton.

Figure 7: In the field with Paxton and James looking at monitoring technologies and deficit irrigation under pivots and drip tape in Lubbock Texas. (Source: Author)

The value of technology and data in semi-irrigated cotton systems lies not in any single tool, but in the integration of monitoring, decision support and operational execution into a coherent management approach. Monitoring reduces the uncertainty inherent in water-limited production; decision-support tools and trusted advisors convert that visibility into sound, timely judgement; and automation ensures decisions are executed with the precision and speed variable conditions demand. Consistent with global experience, the greatest constraint is rarely technological capability, but the confidence to interpret data and act on it decisively. For Australian semi-irrigated cotton systems, closing this gap is a significant opportunity: technology does not simply support water use efficiency, it enables growers to convert variable seasons into genuine strategic advantage.

1.4 Policy: the framework behind farm performance

Improving WUE does not occur in isolation from the broader institutional environment. Water policy, allocation frameworks and regulatory settings determine the value of water, the level of supply certainty and the incentives for improving efficiency within production systems. Decisions growers make are shaped as much by the policy environment as by the agronomic and economic conditions of their farming system. Water governance, the institutional, legal and regulatory structures determining how water is allocated between environmental, urban and agricultural users influences not only availability but the certainty and security with which growers can plan and invest. This section examines that influence through country-level case studies across Australia, the United States (US) and Brazil, and considers the growing role of sustainability frameworks and market access in shaping how water efficiency is valued.

Water in irrigated systems is both a production input and an economic asset. How it is priced, allocated and traded determines not only how much water growers can access, but how efficiently they use it and how confidently they invest in the infrastructure and management that improves its productive use. Where water carries a clear, transparent market value, as it does in Australia's Murray-Darling Basin (MDB) through entitlement trading, growers are incentivised to use it efficiently, because every megalitre has a measurable cost. Where water is effectively unpriced or allocated without clear security of tenure, that incentive weakens. Allocation security matters equally: growers who cannot reliably predict water availability from season to season face a fundamentally different investment calculus than those operating within a secure entitlement framework, and uncertainty, whether from policy reform, environmental water recovery or climate variability can suppress exactly the investment behaviour that efficient water use depends on. As water becomes scarcer and more expensive, the economic pressure to maximise return intensifies, shifting focus from bales/ha to the metric that matters most under constraint: return/ML.

Water policy in practise: Global insights

AUSTRALIA

Australia's MDB is one of the most sophisticated water governance frameworks in the world, and one of the most contested. Its entitlement trading system has created genuine price signals. Temporary water prices in the southern Basin have at times exceeded $500/ML, fundamentally changing how growers value and manage water. But the ongoing program of water buybacks has recovered 1 in 3 litres of irrigation water for the environment, leaving just 28% of average river flows available to water users (National Irrigators Council, 2025). The CSIRO projects the Basin will become hotter, drier and more drought-prone (Murray Darling Basin Authority, 2025). For the cotton industry, this is a two-directional squeeze: agricultural water is being reduced from above by policy and from below by climate. Meeting with Zara Lowien, CEO of the National Irrigators Council (NIC), made clear that Australia is approaching a tipping point where the efficiency gains driven by pricing and tighter allocations are being outpaced by the scale of the resource challenge itself, with implications extending well beyond economics into the resilience of rural communities.

UNITED STATES OF AMERICA

The US shows how differently governance can play out even within one country. In Texas, groundwater from the Ogallala Aquifer operates under the rule of capture, effectively, the first to pump gets it. Without enforceable extraction limits, the aquifer is being drawn down far faster than it recharges. Growers have adapted through deficit irrigation and efficient system design, but the productive life of the resource will still end. Attending the Texas A&M AgriLife Water Symposium made clear that agriculture is no longer even the dominant pressure on the resource, explosive urban population growth is. Mississippi is watching a similar trajectory begin in its alluvial aquifer, and NCAAR, a USDA-MSU research partnership established by Congress in 2017, was created specifically to get ahead of it. The key difference from Australia: efficiency gains in the US are driven by productivity, not price, water is cheap and largely unregulated, a stark contrast to Australia's governance-driven efficiency.

Figure 8: Attending the Texas A&M AgriLife Water Symposium, Dallas TX 2025. Pictured with Drew Gholson and Chris Delhom at NCAAR, Stoneville MS 2025. (Source: Author)

BRAZIL

Brazil's governance challenge is shaped not by scarcity but by the pace of expansion. Water is abundant but unevenly distributed and has historically supported rapid agricultural growth while masking emerging governance vulnerabilities (OECD, 2015). Its permit system — outorgas — mirrors the entitlement logic underpinning the MDB, but water charging (cobrança) remains the exception rather than the rule (OECD, 2017), so the price signal that drives Australian efficiency is largely absent. This matters most in MATOPIBA, where irrigated cotton is expanding rapidly on the Urucuia aquifer and Grande River basin. A 2024 study by Brazil's National Space Research Institute and Stockholm University found this expansion is now running ahead of the resource base, warning that 30–40% of irrigation demand may go unmet by 2040 as aquifer recharge and river flows decline (Martins, et al., 2024). The parallel to the MDB is instructive, but the sequencing is reversed: Australia built governance and pricing first, and efficiency followed under constraint; in Brazil, expansion has come first, and the governance to drive efficiency has not yet caught up.

Figure 9: Meeting at MAPA, the Ministry of Agriculture, Livestock and Food Supply and with the National Farmers union in Brasilia, Brazil 2025 (Source: Author)

Alongside water governance, market access is increasingly shaped by sustainability credentials. Certification frameworks like the Better Cotton Initiative, regenerative agriculture certifications, and supply-chain traceability programs are increasingly used by brands and retailers to verify the sustainability of the fibre they source. Corporate Environmental, Social and Governance (ESG) reporting obligations and emerging green finance incentives are creating a direct line between farm-level management and buyer requirements. The European Union's (EU) Green Deal, whose scale I saw firsthand visiting the EU Parliament and European Commission in Brussels, is the clearest signal of where this trajectory is heading. Its regulatory reach may not extend to Australian agriculture directly, but its influence on the brands and retailers that buy Australian cotton is increasingly material. For Australian cotton, already operating under some of the world's most stringent water governance, this is a genuine competitive advantage, but only if it is measured, communicated and continuously improved. CRDC's Australian Cotton Industry Data Platform, centralising data and automating sustainability reporting, is a direct industry response to that opportunity.

Figure 10: Pictured during GFP with country host Tessa Dimond at the European Parliament and outside the European Commission in Brussels, Belgium 2025 (Source: Author)

Global lessons

The clearest lesson from Australia, the US and Brazil is that policy settings matter. Not abstractly, but in ways that directly shape what growers can plan, invest in and build over time. Where water is secure, tradeable and appropriately priced, growers invest with confidence; where governance is absent or uncertain, that confidence evaporates and the resource itself is often the casualty. Australia shows what well-governed water markets can achieve; Texas shows what happens without governance; Brazil is expanding on an assumption of abundance its own projections say deserves scrutiny. Governance frameworks are far easier to build before a crisis than during one. And for Australian cotton, strong farm management and an enabling policy environment need to keep pulling in the same direction.

Extended discussion of these country-level water governance frameworks and the sustainability and market access landscape is provided in Appendix 2.4.

1.5 People, knowledge and performance

Technology, policy and agronomic knowledge are enablers, but they only deliver their full value when the right people, with the right mindset, are making and implementing decisions. In semi-irrigated cotton systems, the limiting factor in water use efficiency is rarely technical, it is human. The growers who consistently outperform do so not because they have access to better tools or more water, but because they approach uncertainty differently; with clarity about risk tolerance, discipline in decision-making and the confidence to act when conditions allow. It is this capacity to capture upside, manage downside and build resilience over time that separates high-performing systems from the rest.

High-performing systems are rarely the product of a single decision-maker working in isolation. It is reflected in the quality of relationships between growers, agronomists and advisors who collectively translate research, monitor performance and adapt management over time. The best agronomists do more than interpret data and schedule inputs; they challenge assumptions and provide the external perspective that's difficult to generate from within a system. Grower networks and peer learning matter equally. Australian research shows that when producers collaborate and learn from each other's experience, research adoption is more likely to translate from reports into practice (Nettle, Major, Turner, & Harris, 2024).

Barriers to change are rarely about access to information, they're more often about the conditions people act on it. Sunk costs, uncertainty and the perceived risk of change all constrain adoption. Loss aversion compounds this further: growers who've experienced a loss from trying something new are often the most resistant to trying again, not from lack of ambition but because a past loss reshapes how future risk is weighed. Rebuilding that confidence requires demonstration, peer validation and trusted advisor relationships, not just better information. This is where Australia's private consulting sector is a genuine competitive advantage. In the US and Brazil, extension runs predominantly through university and agrochemical/seed company channels, where commercial incentives can limit independence, whereas Australia's model, at its best, is accountable to the grower rather than the product.

In semi-irrigated cotton, decisions are routinely made with incomplete information, and how growers perceive and respond to that uncertainty is one of the most significant determinants of system performance. Australian research has found a disconnect between farmers' climate risk perception and their adoption of climate-smart practices, with regional conditions, policy settings and socioeconomic context influencing adoption more strongly than risk perception alone (Khuraijam, Wechtler, Vaughan, & Luke, 2025). Simply raising awareness of risk isn't enough if the enabling conditions for action aren't also in place. Knowing your numbers is what creates those conditions: growers who understand their true cost of production and break-even point are consistently better positioned to act with confidence under uncertainty, replacing intuitive, emotionally driven decisions with ones grounded in evidence.

The distinction between proactive and reactive management is one of the clearest differentiators of high-performing farms, and it's fundamentally a people characteristic, not a technical one. The tools and frameworks to support proactive decision-making are increasingly accessible, but the limiting factor is the discipline to use them ahead of the decision window rather than in response to it. Proactive management begins before the season: monitoring, water accounting and advisor engagement are completed ahead of the sowing window, because the cost of being unprepared when opportunity arrives is too high. In-season, it's expressed through continuous reassessment of demand against supply; post-season, it becomes retrospective, using yield maps and benchmarking to evaluate what worked. Growers who make proactive decisions, even under uncertainty, subsequently develop stronger risk perception and greater adaptive capacity over time (Wheeler, Nauges, & Zuo, 2021).

Extended discussion on the value of people and decision making is provided in Appendix 2.5.

“Agriculture is a business, understanding your cost of production is everything”

- Jeremy Jack, Silent Shade Planting Company
  Belzoni, Mississippi USA

Decision making: Global Insights

Sitting around the boardroom table with Jeremy Jack, his sister Stacie, and Mississippi State University Extension lead Dr Drew Gholson was one of the most pragmatic conversations of my study tour. The questions weren't about variety selection or irrigation timing, they were about efficiency, return on investment and margin. We weren't there to discuss how to grow the crop, we were there to talk about how to grow the business.

What stayed with me wasn't just the sophistication of the approach, but the transparency with which Jeremy and Stacie shared both the opportunities and the challenges of building a farming business at scale. Silent Shade is a family business that has moved beyond legacy farming to expand rapidly, and what underpins that trajectory isn't a single tool or technology, it's a mindset. Jeremy runs Silent Shade first and foremost as a business, with real-time cost visibility underpinning every in-season decision. Grain marketing is managed entirely in-house, and it's the same discipline that makes that possible: knowing the true cost of production is what allows Silent Shade to market strategically rather than reactively.

What struck me most was the confidence that discipline creates. Jeremy and Stacie weren't guessing at what a decision would cost them- they knew, and that certainty let them act decisively rather than cautiously. That's the same distinction between proactive and reactive management that separates high-performing systems more broadly: the confidence to act comes not from having more information available somewhere in the business, but from having already done the work to know what the numbers mean before the moment requires a decision.

The lesson translates seamlessly to Australian production. In variable, water-limited environments where resource allocation decisions are made under uncertainty, knowing your true cost of production is not simply good accounting, it's the foundation of good management decisions. In semi-irrigated cotton systems, the decision to cut back spend or advance cutout can be as profitable as any agronomic input, but only if the numbers, and the discipline to use them, are already in place.

Figure 11: L-R Drew Gholson, Kate Lumber and Jeremy Jack at Silent Shade head office. (Source: Author)

Ultimately, the preceding levers only translate into water use efficiency gains when people have the mindset, relationships and discipline to apply them.

- Trusted relationships convert research into practice.
- Understanding and managing the psychology of change accelerates adoption.
- Disciplined risk assessment turns uncertainty into a manageable decision rather than a source of paralysis.
- The mindset to act ahead of the season, not in response to it.

Proactive management is not a personality trait; it is a capability built on knowing the business well enough to act decisively before conditions force a response.

Chapter 2- The decision cycle

That proactive capability doesn't operate in the abstract, it's exercised through a recurring cycle of decisions, made at different times, with different weightings, under different degrees of certainty. The grower who plants in November is the same grower who watches a forecast in December, adjusts a watering schedule in February, picks apart a yield map in May, and sits down in winter to ask what they'd do differently next time. Each moment calls on a different kind of judgement, but together they form a single process, the Decision Cycle (Figure 12) which forms the framework behind Chapters 2 and 3 of this report.

These decisions are rarely made with certainty or unlimited resources. Water allocation is variable, seasonal conditions shift without warning, and each choice narrows the options available for the next. Under this constraint, better decisions are the product of disciplined process: planning deliberately, watching closely, adjusting promptly, measuring accurately and learning systematically are the foundations of success season on season. This chapter frames that discipline as a five-stage cycle: Plan, Monitor, Adapt, Evaluate, Learn. Each stage feeds the next, so experience accumulates, informing decisions for the following season.

This pattern is not unique to this study: Australian research on farm resilience identifies adaptive management as a key contributor to farm viability and business continuity (Bardsley, Palazzo, & Putz, 2018). This adaptive process has been shown to operate as a recurring cycle in Australian farming systems more broadly. Growers identify the constraint, address it, and carry the lesson into the next decision cycle, with this pattern repeating across both tactical and strategic timeframes (McKenzie, Joyce, Zander, Wurm, & Caudwell, 2023). The habit of critically evaluating performance and adjusting the system in response was a defining characteristic of the high-performing operators observed throughout this study tour.

Figure 12: Decision Cycle- Plan, Monitor, Adapt, Evaluate, Learn (Source: author).

Stage 1: Plan- set the direction

Planning matches the season's ambition to its resources. Before a single seed goes in the ground, the grower defines objectives, assesses available water and matches ambition to what the system can support. This is also where the production system is designed with parameters like row configuration, variety, area committed, strategy for a constrained allocation and where risks and opportunities are mapped out.

Stage 2: Monitor- build situational awareness

Once the system is designed, the job shifts to building an accurate, current picture of what's happening. This includes monitoring the crop, soil, weather, water, markets, and the technology used to track it. Monitoring doesn't change the plan by itself, but it adds a valuable layer of information to inform decisions. Growers who invest in good monitoring are working with better information when the time comes to adapt.

Stage 3: Adapt- respond to changing conditions

Adaptation is where the plan meets reality. Irrigation timing, nutrition, crop protection, PGR use, those decisions all happen here. These decisions are often multi-factorial and influence one other, causing the need for ongoing adjustment throughout the season.

What makes this stage genuinely difficult is that adaptation rarely offers a clear right answer. It is exercised under incomplete information. A grower with a marginal allocation watching a shifting rainfall outlook must weigh whether to hold the original plan, commit further, or pull back, knowing that each option carries a different amount of risk. Committing further chases upside but deepens the exposure if conditions turn; holding back protects the downside but may concede yield the season could have delivered. There is rarely a way to know, in the moment, which choice will be right in hindsight.

This is also where the cost of indecision becomes real. Delaying a call rarely removes the risk, but usually just narrows the options left available, as the window to act profitably closes. The discipline built in planning matters here because it gives the grower a reference point to be tested against rather than made on instinct alone. Adaptation, in that sense, is not a deviation from the plan but a continuation of it.

Stage 4: Evaluate- measure outcomes

At season's end, the focus shifts to accurate measurement: yield, WUE, profitability, fibre quality, and operational performance, compared against what was planned and expected. This is where the gap between intended strategy and realised outcome becomes visible and where a reliable benchmark matters most. Without one, evaluation risks becoming a story rather than an assessment.

Stage 5: Learn- improve the system

The final stage is what separates a decision cycle from fixed routine and is ultimately what drives continual improvement. Learning means benchmarking results, capturing lessons- both the ones that confirm existing practice and the ones that challenge it, and genuinely adopting new ideas where the evidence supports them. That learning should draw on more than the proceeding season and should include industry trials, emerging technology and benchmarking data from beyond the farm gate to sharpen the scope of what's possible. The cycle only compounds in value if Stage 5 feeds back into Stage 1: where one season's lessons visibly shape the next season's plan.

Three levels of decision, one cycle

The five stages don't carry equal weight. It helps to view the cycle across three levels of decision making, distinguished by frequency and consequence, because the level a decision sits at should determine how much deliberation it gets. Mismatching the two is itself a common source of poor outcomes. This formalises the proactive/reactive distinction introduced in 1.5: work done ahead of the sowing window is strategic, continuous in-season reassessment is tactical, and post-season retrospection is evaluation and learning

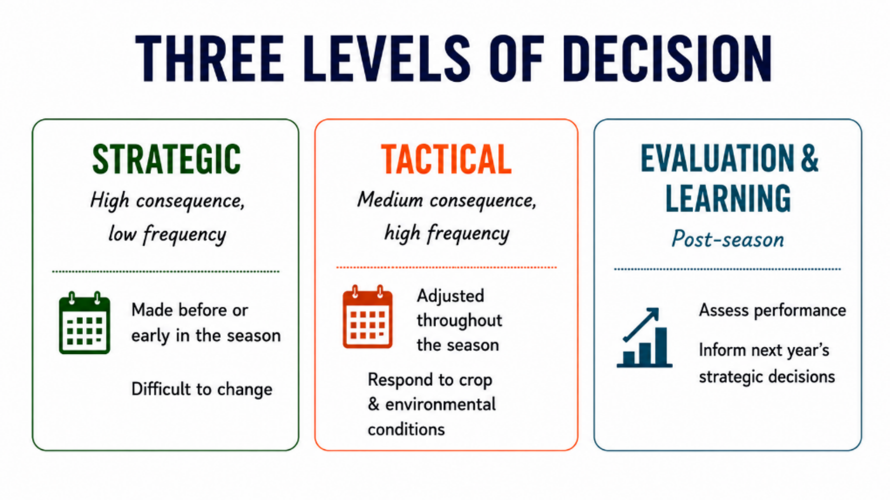

Figure 13: Three levels of decision making (Source: author).

Strategic decisions are predominantly made in the planning stage. They are high consequence, low frequency, made early, and hard to change. These deserve the most deliberate scrutiny, since a mistake here is rarely correctable once the season is underway.

Tactical decisions are where Monitor and Adapt work together. They are medium consequence, high frequency, adjusted continuously in response to crop and environmental conditions. Individually lighter than a strategic call, but collectively decisive in how well a plan is executed. The risk here is less about any single misjudgment than about drift, where a string of small compromises can quickly alter the intended outcome.

Evaluation and learning decisions are post-season, assessing performance accurately and feeding that assessment back into next year's strategic choices. Treating these as a formality rather than a genuine input is how the same avoidable mistakes resurface year after year.

The five stages and the three levels are two views of one process, one organised by *what* is being done, the other by *when* it happens and *how much it costs to get wrong.*

The cycle as a foundation for water use efficiency
Together, these describe a discipline: treating every season as both a production cycle and a learning opportunity. The Decision Cycle doesn't replace the five levers of WUE explored in Chapter 1. It is the process through which decisions about those levers are made, tested, and improved over time. A grower can know every lever available and still under-perform if the process around them is undisciplined. Equally, a grower working with limited tools but a genuine strategic habit will out-improve one who doesn't. That is the foundation built on for Chapter 3.

Chapter 3- The seasonal decision matrix

Knowledge and Process, as set out in the preceding chapters, describe what a grower needs to know and how that knowledge should be utilised throughout a season. A grower does not apply the five levers or work the decision cycle in abstract. Before seed goes in the ground, water availability must be converted into a single, largely irreversible commitment: how much area to plant.

This is the highest-consequence decision a semi-irrigated cotton grower makes each year, not simply because of it's complexity, but because it is made earliest, with the least information, and is the hardest to walk back once made. This chapter works through this decision in full, using real industry gross margin data to test four broad strategies. Area commitment under variable allocation is a systems-level problem before it is a budgeting one, which is why the right answer here is a structured comparison, not an instinct.

Farming systems as the foundation for the decision

Before the area-commitment decision can be modelled, it must be understood as a systems problem. Williams, et al. (2018) provide the clearest evidence base for this. Using a bio-economic, farm-scale model of a mixed irrigated cotton, wheat, maize and dryland sorghum operation in southern Queensland, the study tested how a farm's profitability responds to climate change and reduced water allocation under two adaptation strategies: a less-intensive cotton configuration using wider row spacing and a cap on in-crop irrigations, and a further step that allowed dryland cotton into the rotation alongside that configuration.

The result that matters most for this report is not the specific yield or profitability figures the model produced, but the structural finding underneath them. A farm without access to these configuration options has no choice but to respond to reduced allocation by simply shrinking the irrigated area, while a farm with that flexibility can absorb the same reduction in water with comparatively little impact on profitability. The Darling Downs system Williams et al. modelled could shift between configurations of cotton production- adjusting row spacing, irrigation intensity, and crop mix and in doing so converted a fixed water constraint into a set of design choices.

This is the agronomic justification for treating area commitment as a genuine strategic decision. If a farming system only has one configuration, full irrigation at a fixed area, scaled up or down with whatever water happens to be available that season then the area-commitment decision is not really a decision at all. It is only once a system has multiple genuine configurations available to it, be it minimising area, spreading water across more hectares at a deficit, splitting the farm into differently managed blocks, that the choice between them becomes a strategic lever with its own value, separate from the value of the water itself. Williams et al.'s finding that configurational flexibility preserves profitability under future allocation pressure is the systems-level evidence that this report's central argument rests on. Semi-irrigated cotton, built on rain-grown principles and scaled with irrigation, is itself a configuration choice in exactly this sense. It is one that gives a farm more of the flexibility this study identifies as the difference between an enterprise that is resilient in a dry season and one that simply contracts.

Long-term farming systems work from the CSIRO-led Pampas trial on the eastern Darling Downs (Bell, Whish, & Horan, 2024) corroborates this principle from an independent direction. The Pampas trial is not an irrigation study, it compares dryland cropping configurations (a baseline rotation against systems modified for higher legume frequency, higher crop diversity, higher cropping intensity, and lower cropping intensity) over nine years of field data and a 60-year Agricultural Production Systems sIMulator (APSIM) simulation back to 1957. What it demonstrates, across that full range of seasons, is that no single rotational configuration dominates: the higher-intensity system out-yielded the baseline roughly half the time, mostly in favourable seasons, but produced the lowest returns of any system in around a quarter of periods. In the worst conditions, while the lower-intensity system showed almost the mirror-image pattern, performing comparatively well precisely when the higher-intensity system performed worst. The systems built around greater crop diversity followed a different and more useful shape again: similar downside to the other systems in poor seasons, but disproportionately more upside in good ones, because a wider set of crop options let the system opportunistically capture seasonal conditions that a narrower configuration could not.

The relevance of this finding to the area-commitment decision is structural, not literal. Bell et al. are not studying water allocation in cotton, but they are demonstrating the same underlying principle that Williams et al. establish for irrigated cotton specifically: a fixed, single-configuration strategy will, by construction, win in some seasons and lose in others, while a system built with multiple configurations available to it can be matched to the season as it unfolds, trading a small amount of peak-season upside for a system that performs across a much wider range of conditions.

Preliminary evidence from the industry's own long-term systems trials points in the same direction. CRDC's long-running rotation and tillage trial at the Australian Cotton Research Institute has, over successive seasons, found that minimum-tillage plots consistently out-yielded conventional tillage, with the improvement attributed to better in-crop water recovery. They also found that incorporating maize into the rotation delivered a further, modest, yield gain through gradual improvements to soil structure (CRDC, 2017). The finding speaks to tillage and rotation choice rather than water allocation, but it reinforces the same underlying pattern: farming systems built with more than one configuration available to them consistently outperform those with only one.

This is precisely the logic the hybrid model relies on later in this chapter, not by avoiding risk altogether, but by holding more than one configuration in reserve.

The decision-making process

Reduced to its essentials, the area-commitment decision is answered by three questions, asked in sequence.

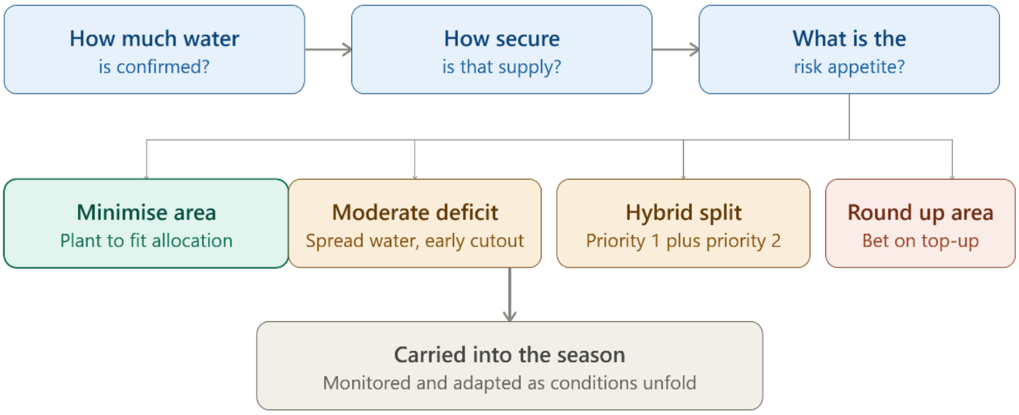

Figure 14: Three questions that shape the four production strategies (Source: author).

The first question is how much water is confirmed, drawn from some combination of stored soil moisture, allocation and on-farm storage. The second is a judgement on how secure that position is, given the catchment and seasonal outlook. The third is personal rather than agronomic. Given that water position and its security, what is the grower's tolerance for risk, in terms of economic exposure, labour and machinery capacity, and appetite for this season's outlook?

These three questions resolve into four broad strategies, each occupying a different position on the same underlying trade-off between certainty and scale:

Minimise area
Plant only what the confirmed water position can fully irrigate, protecting yield potential and return certainty on every hectare sown. This is representative of a traditional 'fully' irrigated system.
Moderate deficit
Spread the same water across a larger area at a planned, moderate deficit, trading yield ceiling for more hectares in production.
Hybrid split
Divide the farm into a priority-one area that receives full water and a priority-two area that is deliberately deficit-irrigated, containing risk to a defined portion of the farm.
Round up area
Plant to the area the grower expects to be able to water in a typical season, accepting the risk that additional water may need to be purchased to finish the crop.

None of these are inherently right, and this chapter does not treat them as a ranked list of recommendations. Each is a defensible response to a different water security position and risk appetite. The value of setting them out side by side is that it forces the comparison to be made explicitly, rather than defaulted into by habit. The strategies above are meaningfully different only if the grower can quantify what each one returns based on their water position, which is precisely what most growers in the industry research survey reported they do not do.

Let's look at the numbers

To test these strategies, the following analysis uses the 2025–26 CottonInfo, AgEcon Cotton Industry Gross Margin budgets for furrow-irrigated and semi-irrigated (double-skip) cotton (Cotton Info, 2026). These independently developed, industry-standard budgets are used throughout this analysis and can be found in appendix 3. This scenario models a grower with 1,000 ML of confirmed water and no certainty of further allocation.

The furrow-irrigated budget reflects its own published five-year average of 6.4 ML/ha applied (7.8 ML/ha sourced, after conveyance losses), returning 12 bales/ha. The semi-irrigated budget reflects its own published target of 3.5 ML/ha applied (4.3 ML/ha sourced), returning 7 bales/ha. To test whether a more moderate deficit performs differently to the full deficit reflected in the published semi-irrigated budget, a moderate deficit scenario of 6.0 ML/ha sourced and 9 bales/ha is also modelled, with its cost structure interpolated consistently between the two published budgets. This is in line with the applied value nominated in the industry research survey. The hybrid strategy splits the confirmed water 70/30 between a priority-one area at full irrigation and a priority-two area at this moderate deficit rate, protecting the bulk of the farm's water security on a known, certain core while exposing only a smaller block to deficit risk. See below:

Table 2: Allocation framework economic analysis (Source: adapted from Cotton Info, 2026)

	1. Minimise area	2. Moderate deficit	3. Hybrid system	4. Round up area
System name	Traditional Irrigated	Semi-irrigated	Irrigated & semi irrigated	Purchase water to finish the crop. If not acquired, early cutout, yield penalty
Area planted	128 ha	167 ha	140 ha P1: 90ha P2: 50ha	145 ha
Area vs Minimise area (control)	0%	+30%	+9%	+13%
Water source	1,000ML (7.8ML/ha)	1,000ML (6.0 ML/ha)	1,000ML P1: 700ML P2: 300ML	1,131ML required 1,000ML secured
Yield	12 bales/ha	9 bales/ha	P1: 12 bales/ha P2: 9 bales/ha	12 bales/ha if water is secured 9.9 bales/ha if water isn't secured
Gross margin/ha	$3,317	$2,800	P1: $3,317 P2: $2,800	$3,317 if secured $2,254 worst case

Total farm gross margin	$425,250	$466,608	$437,658	$465,247 best $326,866 worst
Return per ML ($/ML)	$425	$467	$438	$411 best $327 worst

* Minimise area is traditional fully irrigated system, that forms the standard practise (control)

** Gross margins are variable- cost budgets only

*** All assumptions and costings can be found in Appendix 3.

Moderate deficit returns both the highest total farm gross margin and the highest return/ML of any strategy on these figures, narrowly ahead of round up area's best case on total gross margin, and comfortably ahead of every strategy on return per ML. Minimising area, the standard-practice benchmark, sits second on both measures, with the hybrid split landing between the two, closer to minimising area than to the deficit extreme, reflecting its 70/30 weighting toward full irrigation. It should be noted that the return produced by minimised area matches that of the moderate deficit if it yields 12.5b/ha, which is some valleys would be considered a modest yield. Round up area's best case still returns a total farm gross margin within a few thousand dollars of moderate deficit's, but its return per ML ($411) remains the weakest of any fully committed strategy, and its worst case, an early cutout at 9.9 bales/ha produces both the lowest total gross margin and the lowest return per ML in the table. This is the defining feature of a strategy whose downside depends on the availability and price of water the grower must purchase on the open market.

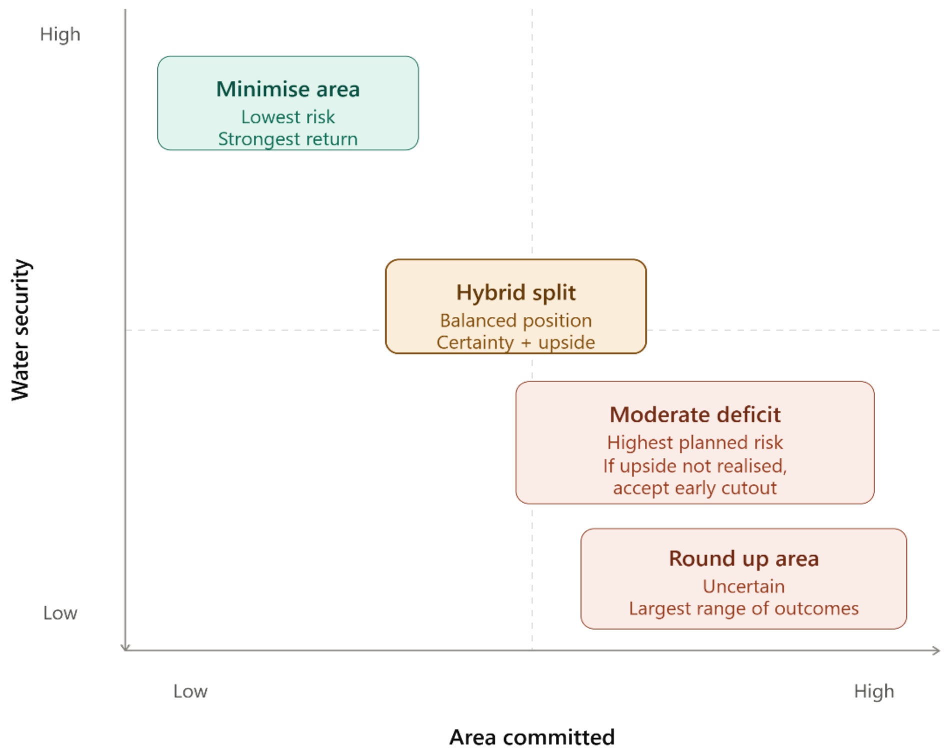

Figure 15: Allocation framework risk analysis- area committed x water security (Source: author).

Read against this matrix, two of the four strategies carry a different kind of risk to the other two. Minimise area and hybrid split both commit only the water already confirmed; their risk is agronomic and financial, not positional. Moderate deficit and round up area both carry a second layer of risk on top of that, but of a different character. Moderate deficit's risk is planned and known in advance: the grower chooses the deficit level and prices the yield trade-off at the point of planting, with the option to adjust in-season if conditions run against the crop. Round up area's risk is unplanned and externally determined: its outcome depends on water the grower does not yet hold, and on whatever price is assigned to that water if it becomes available at all. The two are not equivalent simply because both involve more area than minimise area; one is a risk the grower controls and prices in advance, the other is not.

These figures are illustrative. Every farming system is different, and the value of this framework lies in running the same comparison using your own cost of production and achievable yields, a slight shift in any input can materially change the result. To support this, an Excel workbook has been made publicly available, allowing readers to input and test their own numbers against this format (Lumber, 2026). It can be accessed at More From Every Drop-Semi-Irrigated Strategy Comparison Excel.

The hybrid model: low risk, retained upside

The analysis can not identify a single strategy that wins on every measure in every season. What it does identify is the strategy best positioned to perform consistently across a range of conditions: the hybrid model. By committing the majority of confirmed water to a fully irrigated priority-one area and deliberately deficit-irrigating a smaller priority-two area, the hybrid captures the certainty of minimising area and the scale of moderate deficit, without the exposure that defines round-up area. It does not lead the comparison table on headline return; when using the average parameters defined in the AgEcon Gross Margin budgets. But it offers something the other strategies do not: a contained, known downside on the priority-two area, a genuine pathway to upside if conditions improve mid-season and a farm that remains positioned to respond rather than committed to a single outcome. For growers building semi-irrigated cotton into their system as a deliberate configuration rather than a fallback position, the hybrid model is the structure this research recommends.

The moderate deficit (semi-irrigated proxy) in Table 2: Allocation framework economic analysis rests on a single point. 6.0 ML/ha sourced, returning 9 bales/ha. Table 3 recalculates return/ML across water and yield combinations, using the same costing method.

Table 3: Return/ML across varied water and yield combinations (Source: author).

Water sourced (ML/ha)	8 bales/ha	9 bales/ha	10 bales/ha	11 bales/ha
5.0	$482	$568	$655	$741
5.5	$434	$513	$591	$670
6.0	$394	**$466***	$538	$610
6.5	$360	$427	$493	$560
7.0	$331	$393	$455	$517

** The chapter's chosen point (6.0 ML/ha, 9 bales/ha). The clears the minimise area benchmark of $425/ML by $41/ML.*

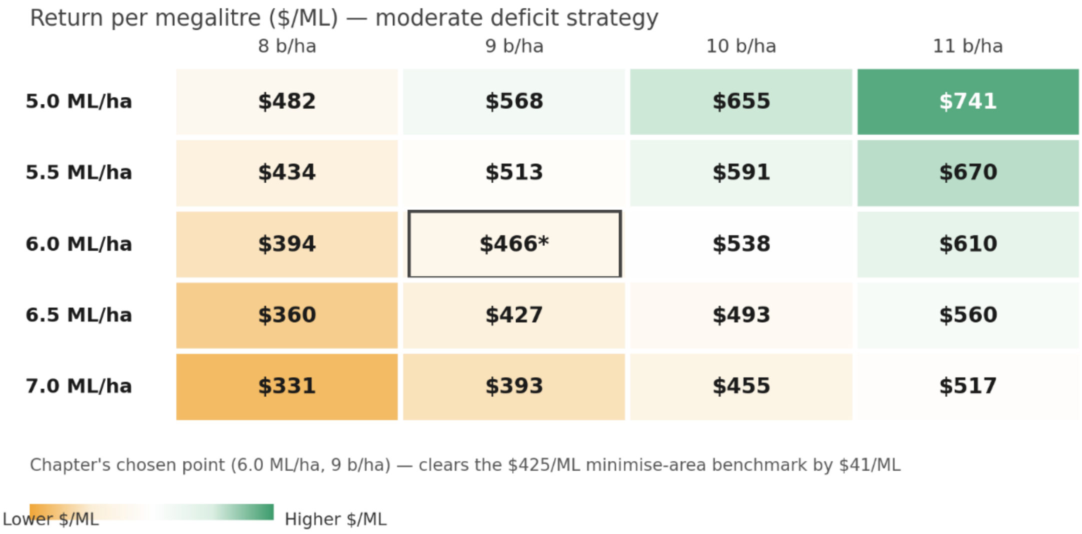

Figure 16: Sensitivity heatmap, return/ML against water and yield combinations (Source: author).

Against the minimise area benchmark of $425/ML, moderate deficit's chosen reference point now clears it by $41/ML ($466 vs $425). The line worth watching sits at the edges of the table, not at the centre: at 9 bales/ha, moderate deficit only falls back to the minimise area benchmark once water use climbs toward 6.5 ML/ha; at 8 bales/ha, that crossover point drops to around 5.6 ML/ha. Within the range tested here, most yield/water combinations clear the benchmark comfortably, it is only the lower-yield, higher-water corner of the table where the deficit stops paying for itself. The published semi-irrigated budget's more severe deficit (4.3 ML/ha, 7 bales/ha, $471/ML) now sits close to, rather than clearly ahead of, the chapter's chosen reference point both represent configurations where the deficit has been pushed far enough to pay off; it is the shallower end of the range, not the published budget's severity, that marks where a deficit stops earning its keep.

This demonstrates the value of the analysis. The true value of this framework comes when this comparison is made with real numbers from your own system, because a small shift in where the deficit lands can change the answer entirely.

This is the basis for positioning the hybrid model as the preferred structure. Not because it wins by any given metric, but because of what it retains. The priority-two area can be topped up later in the season if conditions allow, giving the strategy a genuine pathway to upside without exposing the whole farm to that risk. The single-season expression of the same principle Williams et al. identify at the whole-farm level and Bell et al. demonstrated over six decades of seasons is that holding more than one configuration in reserve is what allows a system to perform across a wide range of conditions.

This is also where the case for semi-irrigated cotton as a deliberate system choice, rather than a fallback position, is made most clearly. A farm that has built semi-irrigated cotton into its rotation as a genuine configuration, not as a reduced-intensity substitute for furrow-irrigated cotton, already holds the priority-two option that the hybrid model depends on. The decision this chapter describes is easiest to make for the grower who has already done the systems-level work described in Chapter 1.2 and hardest for the grower facing it already under pressure, with only one configuration available to them.

What this looks like on a farm that has built the priority-two option before a dry year drove urgency is the subject of the case study below.

Case Study: Mick Humphries, Mallawa NSW Australia

Mick Humphries' property Chesney provides a compelling example of how the principles discussed in this report translate into real-world decision making under constraint.

Located at Mallawa in northern NSW, the property runs irrigated and dryland farming operation centered around cotton production. Historically an irrigated enterprise dominated by cotton production, persistent disease pressure (Verticillium wilt) has made back-to-back production challenging, prompting a fundamental rethink of how the system generates returns from its water and land assets.

Mick's response has been to rotate into non-host crops to manage disease pressure, while restructuring the irrigated cotton area into a two-tier production strategy, aligned with the hybrid strategy discussed. The priority one area is managed for unconstrained irrigated cotton production on 1m hills and priority two area is managed as a semi-irrigated system in standing stubble under skip row configurations. Configuration is matched to water availability, with double skip for low water input scenarios, single skip for moderate and solid plant where allocation supports it. The guiding metric throughout is return per megalitre rather than yield per hectare, a deliberate reframing that reflects the system's water constraint.

As discussed in Chapter 1.2 planting into a full profile and into moisture is a core principle. This prioritises early root development and preserves irrigation allocation for flowering and boll development rather than committing water to establishment. Agronomy is similarly efficiency-focused, with systematic growth regulation, early nutritional investment and an aggressive approach to first irrigation timing to drive root exploration.

Looking ahead, Mick's long-term vision for Chesney is a fully integrated system of CTF, reduced tillage and retained stubble, moving toward supplementary irrigation rather than fully irrigated production on a portion of country to maximise planting flexibility across a wider range of seasonal conditions. It is a vision that reflects the broader trajectory of the industry- building systems that perform consistently, not just in good years.

Full case study available in Appendix 4.

Mick’s system is not an outside example chosen to illustrate this report’s argument after the fact. It reflects extensive collaborative research between Mick and I (as his agronomist), developed alongside the thinking set out in this chapter rather than independently to it. That relationship is worth being transparent about before broadening the lens: Chesney is a deeply considered application of the framework, not a blind test of it. The question that still needs answering is whether this approach reflects where the wider industry sits. That question is best answered by returning to the survey evidence in appendix 1.2 that grounded this research in the first place.

Industry grounding

To test whether this chapter's conclusions match how the industry thinks about this decision, this report drew on the targeted survey of Australian cotton growers, agronomists, and researchers and industry/extension personnel as provided in Appendix 1.2.

That result is a genuine divide in how respondents understand semi-irrigated cotton's role. A meaningful share of growers described it in defensive terms. A fallback adopted once full irrigation is no longer achievable, accepted reluctantly rather than chosen. Researchers and agronomists, by contrast, more often described the same practice in a different light. As a deliberate design choice suited to any operation carrying more water entitlement than it has irrigable land to use it on, regardless of whether allocation is tight in a given year.

Much of that divide comes down to a mismatch between perceived risk and genuine risk, and the numbers worked through earlier in this chapter speak to both sides of it. A grower who responds to a tight allocation by simply reducing the fully irrigated area feels like they are taking the safe option. The system is familiar, the agronomy is unchanged, and the gross margin table above confirms that minimise area is, on paper, both the safest and can be the best-performing strategy of the four. This result is a snapshot of a single, fixed water position, and it carries a genuine risk the table itself does not show: a farm planted to exactly fit its confirmed allocation has no planted area left to direct water to if the season improves. If there is significant in crop rain or further allocation is released, that water can only be used to finish the crop already in the ground, there is no additional area able to capture it. The hybrid split, by contrast, is built around exactly that possibility. Its priority-two block is deliberately watered in deficit, so when conditions allow, it is there to realise upside that minimised area has no way to capture. The discomfort some growers report toward the hybrid tracks the unfamiliarity of deliberate deficit irrigation on part of the farm, not the comparative position each strategy leaves them in if the season turns favourable.

This is not a disagreement about the practice itself so much as a disagreement about its purpose, and it matters because the two framings lead to different decisions in the same season. A grower who sees semi-irrigated cotton purely as a fallback has little reason to build the priority-two block the hybrid model depends on until a dry year forces the question, by which point the option is hardest to set up well. A grower who treats it as a standing configuration, in the way Chesney's two-tier system does, holds that option before the season makes it urgent. This chapter's analysis and the survey's deliberate-design respondents arrive at the same conclusion by different routes, one from a gross margin comparison, the other from commercial experience: semi-irrigated cotton earns its place in the system before the dry year, not because of it.

Area commitment is the one decision in this report that cannot be revisited once made, which is exactly why it deserves more than instinct. The evidence in this chapter points in one direction from three different angles: farming systems research shows that flexibility, not any single configuration, is what lets a system absorb a poor season without simply contracting. The worked numbers show that no strategy dominates outright, and a very small shift in result, be it yield or water used, will greatly influence the outcome. The industry's own divide on this question tracks a confusion between what feels safe and what actually is. Read together, they arrive at the same conclusion. The value of semi-irrigated cotton, and of the hybrid model built around it, is not what it returns in any one season, it is the resilience and optionality it holds in reserve for the season that does not go to plan. A farm that has built that option in before it is needed is making a structural decision. A farm reaching for it for the first time under pressure is hoping for the best.

This seasonal decision matrix is where Knowledge and Process stop being frameworks and become a single, irreversible number of hectares. The five levers shape what a grower knows going into the decision; the decision cycle shapes how that knowledge is used once conditions start to move. But neither operates in the abstract, they resolve, once a season, into the choice this chapter has worked through. That choice is the clearest test of this report's central argument. A farm that has built semi-irrigated cotton into its system as a genuine configuration, not assembled it under pressure, is the farm for which minimising area, moderate deficit, and the hybrid split are all genuinely available options rather than one default and two afterthoughts. The evidence set out above, from farming systems research, from the worked gross margins, and from the industry's own divided view of what semi-irrigated cotton is for, all points the same way: the value of the practice is not realised in the season it is needed, it is realised in the seasons before, when the option is built rather than reached for. What that means in practice, for the grower, the agronomist, and the industry more broadly, is the subject of the recommendations that follow.

Conclusion

Climate variability has long been a defining feature of Australian agriculture. The increasing magnitude and unpredictability of climatic events are presenting new challenges for farm management and decision-making. Meeting this requires a shift towards adaptive, responsive and data-informed management systems, the foundation for improving WUE and building the resilience needed to sustain cotton production in water-limited environments.

This report has explored the opportunity and positioning of semi-irrigated cotton within that shift. The intent is not to frame semi-irrigation as reduced intensity, but as a deliberate strategy for scaling up production, capturing opportunity when conditions allow, and preparing for low or no allocation years as a known and recurring feature of the system. Some systems already operate this way as a matter of course; for most Australian growers, though, it may need to become part of the strategy moving forward, out of necessity as much as opportunity, from both a profitability and resource availability standpoint. Semi-irrigated cotton should build on rain-grown principles, then scale up, with irrigation reducing risk and improving the consistency of the result.

The five levers explored in this report: plant management, farming systems, technology and data, policy, and people do not operate in isolation. A soil moisture sensor is only useful if a grower has the confidence to act on what it shows. A well-designed system still depends on good plant management decisions in season. Policy settings determine the return on every efficiency gain made at the paddock level. And the people managing the system determine whether any of it translates into results. Lifting WUE is less about optimising any one lever, and more about understanding how they interact and where growers and advisors can intervene to greatest effect.

Underpinning all of this is adaptive management. This was the defining characteristic of the high-performing operators observed throughout this study: disciplined risk assessment that turns uncertainty into a manageable decision, and a proactive approach that creates the time to respond to variables before they become constraints. Nowhere is this more evident than in the area-commitment decision itself, a systems-level problem before it is a budgeting one, and one that calls for the same structured comparison rather than instinct. If a system has only one configuration, full irrigation at a fixed area, scaled with whatever water is available, the decision is not really a decision at all. It becomes a genuine strategic lever only once multiple configurations exist, and this study identifies that flexibility as the difference between a business that is resilient in a dry season and one that simply contracts. The choice rests on three questions: how much water is confirmed, how secure that position is, and the grower's tolerance for risk.

Weighing those three questions against farming systems research comparing performance, no single allocation strategy wins every season. Through agronomic and economic review, the research supports transitioning to a hybrid model as water availability declines, where most confirmed water is committed to a fully irrigated priority-one area, with a smaller deficit-irrigated priority-two area, providing a contained downside, genuine upside if conditions improve, and a farm genuinely positioned to respond as the season progresses.

Every system looks different, and the way these principles are applied will vary with the resources and constraints of individual businesses, but the key challenges and opportunities are consistent. The intent of this work is to provide guide rails that help growers materialise upside and manage downside, improving the reliability and repeatability of outcomes that underpin adoption and long-term profitability.

Research creates value when it changes a decision. Over the course of this Scholarship, it changed mine: how I weigh evidence against instinct, how I synthesise information into decisions, and how I talk to growers about risk. That, ultimately, is the measure I'd want this report held to.

Recommendations

Semi-irrigated cotton offers Australian growers a genuine opportunity to lift WUE and improve profitability in an increasingly water-limited system. The recommendations of this report are as follows:

Manage the crop to the water available: Use in-season monitoring to track crop development against water availability and adjust management accordingly. Don’t underestimate the value agronomic decisions play in influencing crop water use, stress response and ultimately yield.

Prioritise a systems-based approach: Preparing for low or no allocation years should be treated as a known feature of the system, not an exception. In dryland farming, we are disciplined about prioritising rotation, CTF and stubble retention to drive water storage, the same discipline should extend to irrigation country. Area not prepared for cotton in the coming season should still be brought into the rotation, whether irrigated or dryland, winter or summer. Stored water gives you options and increases planting opportunities in the seasons that follow.

Treat area commitment as a strategic decision, not a default. Assess confirmed water, the security of that position, and your own risk tolerance each season, and compare configurations rather than defaulting to the same area commitment every year regardless of conditions.

Invest in the confidence to act, not just the tools. Monitoring and decision-support technology only creates value when growers trust it enough to act on it. Prioritise building confidence through education, trials or trusted advisor input, alongside any investment in the technology itself.

Stay engaged with the policy environment. Water policy and allocation frameworks directly shape the value of water and the incentives to improve efficiency. Growers and advisors who understand and engage with this environment are better placed to anticipate change rather than simply respond to it.

Build a team of trusted advisors: The best advisors do more than interpret data and schedule inputs, they challenge assumptions and provide the external perspective that's difficult to generate from within a business. Understanding what drives performance is what separates businesses that improve over time from those that don't.

Know your numbers: Understand your true cost of production. This replaces intuitive, emotionally driven decisions with ones grounded in evidence, and is the foundation that allows growers to act decisively under uncertainty. It also allows you to invest with confidence. A clear understanding of return on investment lets you back the technology, infrastructure and inputs that lift performance and drive efficiency.

Prioritise innovation: Trial new practices, technologies and strategies on your own farm, engage with local grower groups, and stay abreast of current research, so you are positioned to adopt and adapt as new opportunities emerge.

Together, these recommendations reflect a simple shift in mindset: from managing semi-irrigated cotton as a response to conditions, to designing it as a deliberate system built for them.

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Appendix 1.1: Row Configuration

COTTON SKIP ROW CONFIGURATION OVERVIEW

Different row patterns to manage plant population and water use

CONFIGURATION NAME	ROW PATTERN VISUAL	PATTERN (PLANTED × SKIPPED)	PLANTED AREA (%)
SOLID PLANTED No rows skipped		No rows skipped (Every row sown)	100%
SINGLE SKIP 2 rows planted, 1 row skipped		2 rows planted, 1 row skipped	66.7%
ALTERNATE ROW (1 IN 1 OUT) 1 row planted, 1 row skipped		1 row planted, 1 row skipped	50.0%
DOUBLE SKIP 2 rows planted, 2 rows skipped		2 rows planted, 2 rows skipped	50.0%
SUPER SINGLE 1 row planted, 2 rows skipped		1 row planted, 2 rows skipped	33.3%

Source: author

Appendix 1.2: Industry Survey – Methodology and Findings

A targeted survey was distributed across the Australian cotton industry to capture practical, on-the-ground perspectives on decision-making for semi-irrigated cotton production under water-limited conditions. The survey was structured into three respondent groups to reflect differing vantage points across the supply chain: growers, who carry direct on-farm decision-making and financial risk; agronomists and private consultants, who advise across multiple operations and farming systems; and researchers, extension officers and other industry personnel, who bring a broader systems and research perspective. This structure allowed common themes to be identified and cross-validated across perspectives, while also surfacing points of genuine difference in priorities and risk framing.

Respondent profile

A total of 29 responses were received: 14 from growers, 9 from agronomists and private consultants, and 6 from researchers, extension officers and other industry personnel. Respondents were drawn from across the major cotton-growing valleys of New South Wales and Queensland, providing geographic representation across a range of production systems, soil types and rainfall zones.

Table 1. Respondent profile by group

Respondent group	n	Primary regions represented	Scale of operation / experience
Growers	14	Upper Namoi (4), Gwydir Valley (2), Macquarie Valley (2), Northern Australia (2), Murrumbidgee (2), Darling Downs (1), Macintyre Valley (1), Murray (1)	Annual cotton area: <250ha (1), 250-500ha (5), 500-1000ha (5), >1000ha (3)
Agronomists / private consultants	9	Macintyre Valley (3), Gwydir Valley (3), Mungindi (3), Murrumbidgee (3), Lachlan Valley (2), Lower Namoi (2), Upper Namoi (2), Western Darling Downs (1)	Annual area consulted on: 2,500-5,000ha (5), 5,000-10,000ha (4)

Respondent group	n	Primary regions represented	Scale of operation / experience
Researchers / extension / industry personnel	6	Namoi Valley-based, with state-wide and national coverage	Industry experience: >20 years (4), 5-10 years (1), 3-5 years (1); roles spanning extension, research management, farming systems research and marketing

Growers and agronomists were predominantly drawn from mixed irrigated/dryland operations, with the majority reporting some prior experience with semi-irrigated or supplementary irrigation systems, either through direct production or in-season trial work.

Measuring and tracking water use

Respondents were asked how water use is best measured and tracked on farm. Responses converged on two complementary levels of measurement: whole-farm accounting (storage volumes, pumped megalitres and assumed system losses) and field-level measurement (flow meters, soil moisture probes and, where overhead irrigation is used, direct output metering). Several agronomists and researchers noted that whole-farm accounting is essential for capturing transmission and storage losses, which can represent a substantial proportion of total water use and are otherwise invisible at the field level.

Table 2. Approaches to measuring water use, by respondent group

Respondent group	Common approaches reported
Growers	Field-level metering through pumps and overhead irrigators; whole-farm balance (water pumped minus estimated losses); soil moisture probes under overhead systems; dam/storage monitors; multiple meters reconciled at season end
Agronomists	Whole-farm water balance accounting for assumed losses; field-level metering combined with soil moisture probe data (installed prior to first irrigation where possible); evaporation sensors; comparison of ML pumped against ML in storage at defined points in the season
Researchers / industry	Emphasis on whole-farm accounting to capture system and storage losses; combination of pump meters, rain gauges, channel and storage sensors, soil moisture probes and canopy temperature sensors; satellite monitoring tools also referenced

Drivers of water use efficiency

The cost and scarcity of water was identified as the dominant driver of WUE across all three respondent groups, closely followed by irrigation infrastructure condition, system losses and irrigation timing. Growers and agronomists placed particular emphasis on minimising transmission and storage losses, while researchers highlighted that over-irrigation in seasons of good water availability remains a significant and under-addressed inefficiency. There was broad agreement that WUE outcomes are ultimately governed by the irrigator's skill and decision-making as much as by infrastructure or technology.

Table 3. Key drivers of water use efficiency, by respondent group

Respondent group	Most frequently cited drivers
Growers	Cost and return on investment; irrigation layout and infrastructure; growing the highest-yielding crop achievable; cost of water delivery; balancing yield against water input; labour and system constraints
Agronomists	Irrigation infrastructure and storage condition; crop rotation and fallow management; irrigation timeliness; soil type and structure; sound agronomic execution ("doing everything right" to grow a high-yielding, efficient crop); grower/manager culture and attention to detail
Researchers / industry	Water scarcity and price, with continued allocation reductions and buybacks; transmission and storage losses, particularly from over-irrigation; farm scale, with very large operations harder to manage well; irrigator judgement and timing relative to fixed scheduling

Benchmarking water use efficiency

The majority of growers surveyed do not currently benchmark WUE on farm but expressed a clear interest in doing so, whereas benchmarking was more established practice amongst agronomists. Researchers were broadly supportive of benchmarking as a valuable diagnostic tool, although it was noted that bales per megalitre can be a misleading proxy for true water use efficiency, as improvements often reflect underlying agronomic or seasonal factors rather than water management in isolation, and that comparing performance across enterprises (rather than within one enterprise over time) is particularly difficult.

Table 4. Current WUE benchmarking practice, by respondent group

Respondent group	Yes	No, but interested	No
Growers (n=14)	6	6	2
Agronomists (n=9)	7	1	1
Researchers / industry (n=6)	5*	0	0

*Researcher responses to this question were qualitative rather than strictly yes/no; all considered benchmarking achievable and valuable in principle, with caveats regarding methodology and comparability noted above.

Strategies for managing reduced water allocation

Growers and agronomists were asked how they manage water in years of reduced allocation, with the option to select multiple strategies. The most commonly selected approach by both groups was to plant a lower area with an adequate or full water budget per hectare, reflecting a preference for certainty over area. The option to manage a moderate area as a deliberate semi-irrigated crop, or to plant into irrigated country as a dryland crop and irrigate opportunistically, were the next most frequently selected strategies.

Table 5. Selected strategies for managing reduced water allocation

Strategy	Growers (n=14)	Agronomists (n=9)
Plant a lower area with an adequate/full water budget (ML/ha)	10	8
Plant a moderate area on a reduced budget, intending to purchase water or secure a pumping opportunity	5	4
Plant crop in irrigated country as dryland and irrigate if the season allows	5	3
Plant a moderate area on a reduced allocation, managed deliberately as a semi-irrigated crop	1	3
Plant a larger area on a low budgeted water input	0	2
Do not plant the crop at all	1	0

Note: figures reflect the number of respondents selecting each option; respondents could select more than one strategy.

Row configuration and water budgets for semi-irrigated cotton

Single skip (or 60-inch) configuration emerged as the preferred row arrangement for semi-irrigated cotton across all three respondent groups, balancing plant population against improved root access to the skip row and compatibility with existing harvest infrastructure. Double skip configurations were generally viewed as more appropriate to dryland systems due to the lower plant population achievable, while solid 1m configurations remained preferred on soils with lower water-holding capacity or where contractor/harvest equipment could not accommodate a skip configuration.

Table 6. Preferred row configuration, by respondent group

Respondent group	Preferences and reasoning
Growers	Mixed preference across solid 1m, single skip and double skip, with the choice strongly tied to soil water-holding capacity, available machinery and contractor compatibility. Several noted commercial seed technology fee structures as an unexpected influence on configuration choice

Respondent group	Preferences and reasoning
Agronomists	Single skip or 60-inch favoured by the majority, on the basis that both retain roughly two-thirds of a solid plant stand while allowing root development into the skip row; double skip viewed as more suited to dryland due to low population; configuration also depends on contractor harvest capability
Researchers / industry	Single skip most preferred, for improved space and rainfall utilisation; final choice noted as dependent on soil type (plant available water capacity), seasonal outlook, target yield and the limits imposed by available machinery

Respondents were also asked how many megalitres per hectare they consider manageable for a semi-irrigated crop. Responses converged on a working range of approximately 3-6 ML/ha, typically structured as a water-up event followed by one to three in-crop irrigations. Respondents across all groups were consistent in noting that this budget is only workable when supported by an adequate starting soil moisture profile and reasonable in-crop rainfall; without this, the system was widely considered not worthwhile.

Table 7. Reported manageable water budget for semi-irrigated cotton (ML/ha)

Respondent group	Reported range
Growers	2.5-6 ML/ha (most commonly 4-5 ML/ha), generally water-up plus 1-3 in-crop irrigations
Agronomists	3-7 ML/ha depending on target yield; water-up plus 1-4 in-crop irrigations where a single skip configuration is used
Researchers / industry	2-5 ML/ha; several noted that above approximately 7 ML/ha with high application efficiency, a crop functions as effectively fully irrigated rather than semi-irrigated

Decision triggers and key challenges

A consistent cluster of conditions was identified across respondent groups as the key triggers for electing to plant a semi-irrigated crop, and a corresponding set of challenges that temper enthusiasm for the system.

Table 8. Reported triggers and challenges for semi-irrigated cotton

Triggers to plant	Key challenges identified
Good starting soil moisture profile (typically following fallow)	Variable, unpredictable seasonal results tied to in-crop rainfall
Favourable summer rainfall forecast	Limited reliability of medium- and long-range weather forecasting
Standing stubble or good ground cover	Grower risk appetite and balance sheet/debt exposure
Constrained or high-cost water allocation	Machinery and contractor compatibility with chosen configuration

Triggers to plant	Key challenges identified
Supportive commodity price	Soil type limitations (low water-holding capacity, drainage)
Favourable planting opportunity/timing	Risk of reduced rotation flexibility in following seasons

A minority of growers indicated they would not consider semi-irrigated cotton under any circumstances, citing the financial risk relative to simply trading water allocation on the temporary market, or soil types considered unsuitable for anything other than full irrigation.

Stubble retention, direct drilling and crop rotation

Stubble retention and direct drilling into standing stubble was widely supported in principle across all groups, with a majority of growers and agronomists already practising it or actively working toward it. The primary management constraints identified were furrow renovation for flood irrigation, nitrogen management and, in several cases, herbicide-resistant weed pressure that had previously led growers away from the practice. Cotton-cereal rotations (both dryland and irrigated winter cereal) were the most commonly reported rotation, often supplemented with legumes, cover crops or summer cereal depending on water availability and disease pressure, particularly Verticillium wilt and black root rot.

Use of plant growth regulators

PGR use to manage canopy architecture under limited water was reported as near-universal practice amongst both growers and agronomists, with 12 of 14 growers and all 9 agronomists surveyed using PGRs in limited-water scenarios. Notably, one researcher response cautioned against this as a strategy for reducing water use itself, on the basis that water use is fundamentally a function of leaf area, temperature and season length, and that PGRs should be applied in response to observed plant condition rather than as a fixed seasonal programme regardless of need.

Identified knowledge gaps and proposed research questions

When asked what they would like to understand more about, and what research questions should be prioritised, respondents raised a consistent set of themes, summarised in Table 9.

Table 9. Priority knowledge gaps and proposed research questions, by respondent group

Respondent group	Priority research themes raised
Growers	Steering crop physiology on minimal water; gross margin comparisons of semi-irrigated versus fully irrigated production; optimal row spacing and yield outcomes on wider rows; minimum viable water use; interaction between cover cropping and semi-irrigated systems; whether crop rotation flexibility is compromised by semi-irrigated layouts
Agronomists	International techniques for water-limited irrigation in other cotton or field crop systems; precise irrigation timing relative to growth stage with only 2-3 available waters; interaction between disease risk and reduced-frequency irrigation; root architecture development under wider row spacing and its effect on water and nutrient use efficiency
Researchers / industry	A clearer, shared definition of “semi-irrigated” or “supplementary irrigation”, given the term was found to carry different meanings across respondents; optimal plant population for varying water scenarios; integration of moisture probes, canopy temperature sensors and ETc data into a unified decision-making framework; international case studies (Israel specifically suggested) on intensive water-limited production systems

Taken together, the survey responses point to a divide in how semi-irrigated cotton is currently framed within the industry. For a portion of growers, it is principally a risk-mitigation and cost-saving response to reduced water allocation. For others, and for the majority of researchers and agronomists consulted, it represents a deliberate system design choice suited to operations holding more water entitlement than irrigable land. This distinction, together with the specific knowledge gaps identified above, has directly informed the structure and direction of the research presented in this report.

Appendix 2.1: Extended Plant Management Research

Plant Management

Plant management is a critical lever for maximising productivity in semi-irrigated cotton systems, governing the crop's physiological capacity to capture, utilise and convert water into yield. Although water availability constrains production potential, variation in crop performance is greatly influenced by how the plant responds to water deficit and environmental stress, and by the management decisions that shape that response.

While physiological processes like transpiration and stomatal conductance underpin the biological determinants of WUE. In semi-irrigated systems where water availability rarely aligns with full crop demand, agronomic decisions play a critical role in influencing crop water use, stress response and yield optimisation. This spans the following domains:

- Canopy management and the use of plant growth regulators (PGRs)
- Biomass accumulation and nutrient partitioning
- Root architecture and soil water extraction
- The sensitivity of yield development to stress timing and intensity
- Effective water budgeting
- The role that breeding plays in traits like determinacy, boll accumulation and quality attribute stability.

As a result, improving WUE is not solely a function of water availability, but of how effectively management aligns crop physiology with the constraints of the production environment. This creates a practical opportunity to optimise plant performance and improve productivity, resilience and profitability under water-limited conditions.

Plant x environment interactions

Cotton production in semi-irrigated systems is shaped by a complex interplay between crop physiology and the surrounding environment. Temperature, vapour pressure deficit (VPD), solar radiation and soil water availability all influence the plant's capacity to grow, reproduce and convert resources into yield. Central to this interaction is the plant's ability to regulate water use in response to environmental signals, a function governed primarily by stomatal behaviour.

Regulation and the Carbon–Water Trade-off

Stomata are pores on the leaf epidermis that regulate gas exchange between the plant and atmosphere, balancing carbon dioxide (CO_2) uptake for photosynthesis against water loss through transpiration. Stomatal conductance describes the degree to which stomata are open and thus the rate at which gases and water vapour move through them. In water-limited environments, stomatal regulation becomes a critical determinant of WUE, governing the trade-off between maintaining photosynthetic carbon assimilation and conserving soil water reserves (Farquhar & Sharkey, 1982).

Under declining soil moisture or elevated atmospheric evaporative demand, stomata partially or fully close to reduce transpiration and limit plant water loss. While this response conserves water in the short term, prolonged stomatal closure restricts CO_2 uptake, reducing photosynthetic rate, biomass accumulation and ultimately yield potential (Lawson & Blatt, 2014). The magnitude of this response is further compounded by high VPD conditions, which increase the vapour pressure gradient between the leaf and atmosphere, accelerating water loss and intensifying the demand for stomatal regulation.

Source–Sink Dynamics Under Water Deficit

Water deficit stress influences cotton productivity through its effect on carbohydrate production, translocation and fruit retention. As soil water becomes limiting, reductions in stomatal conductance constrain photosynthetic activity, restricting the supply of assimilates available to the plant (Lawson & Blatt, 2014). This reduction in source capacity has direct consequences for reproductive development, where demand from squares, flowers and developing bolls is high.

Established bolls generally maintain stronger sink strength and are more resilient to assimilate limitation, while early-stage bolls (3–5-day flower bolls) are considerably more vulnerable to carbohydrate shortfall and the hormonal changes associated with stress (Baker & Baker, 2010). As a result, water deficit occurring during squaring, flowering and early boll development can increase fruit abscission, reduce boll number and significantly limit yield potential.

This source–sink vulnerability underscores the importance of irrigation timing in semi-irrigated systems. Avoiding severe stress during key reproductive windows is critical to maintaining assimilate flow, preserving boll retention and optimising water productivity. In environments where irrigation supply rarely aligns with full crop demand, understanding these physiological thresholds is essential for making informed decisions about when and how much water to apply.

Plant architecture and canopy management

Crop architecture plays a significant role in determining how efficiently water is converted into yield. In cotton, canopy structure influences light interception, radiation use efficiency, transpiration demand, canopy microclimate, fruit retention and the partitioning of assimilates between vegetative and reproductive growth. Canopy management becomes particularly important in semi-irrigated systems, where maintaining an appropriate balance between vegetative and reproductive growth is critical to maximising both WUE and harvest index.

Indeterminate Growth and the Vegetative–Reproductive Balance

Cotton's indeterminate growth habit, characterised by an extended and overlapping flowering and fruiting period, presents both opportunity and risk in water-limited environments. While continued vegetative growth can provide resilience following transient stress events, excessive canopy development increases transpirational demand and may divert assimilates away from reproductive fruiting structures. This can reduce fruit retention, delay maturity and ultimately lower harvest index and WUE, particularly where late-season water availability is constrained (Bange & Constable, 2015). The risk is compounded under high vapour pressure deficit conditions, where a larger, more open canopy increases the crop's exposure to atmospheric evaporative demand, accelerating water loss at the very time that soil water reserves may already be under pressure.

Plant Growth Regulators and Canopy Manipulation

Plant growth regulators (PGRs) are an important management tool for manipulating canopy architecture in semi-irrigated cotton systems. Mepiquat chloride, a gibberellin biosynthesis inhibitor, is commonly used to reduce internode elongation and moderate excessive vegetative growth, redirecting biomass allocation toward reproductive development. A more compact canopy can improve light penetration, reduce unnecessary transpirational water loss and support fruit retention where water supply is limited (Bednarz, Nichols, & Brown, 2006) (Nichols, Snipes, & Jones, 2003).

However, the objective is not simply vegetative growth suppression, but the optimisation of canopy function relative to seasonal yield potential and available water. The interaction between PGR application and crop water status requires careful consideration. Under moisture stress, cotton already undergoes natural growth retardation, and the application of PGRs in this context can compound growth suppression, reducing leaf area and photosynthetic capacity below levels required to sustain adequate boll fill (Dodds, et al., 2010). Effective PGR management therefore requires an understanding of current crop water status, growth stage and seasonal outlook, with application decisions integrated into the broader irrigation and water strategy.

Harvest Index as a Framework for WUE

Harvest index explains the proportion of total above-ground biomass converted into harvestable lint yield and provides a useful framework for evaluating the efficiency of biomass partitioning in water-limited systems. In semi-irrigated cotton, improving WUE is not a function of maximising total biomass production, but of ensuring that biomass accumulation is efficiently directed toward reproductive output. Canopy management practices that moderate vegetative growth, improve assimilate partitioning and support boll retention are therefore direct levers for improving harvest index and, by extension, water productivity (Leffler & Tubertini, 1976) (Constable & Rawson, 1980). This framing reinforces the value of PGR use as an agronomic tool not merely for growth control, but for aligning crop physiology with the constraints and opportunities of the production environment.

Root architecture, Soil water extraction and irrigation strategy

While canopy architecture influences crop water demand, root system function determines the crop's capacity to access and utilise available soil water. In semi-irrigated cotton systems, where stored soil moisture and limited irrigation must be strategically managed, root development plays a critical role in both crop resilience and WUE. A well-developed root system improves the crop's capacity to explore a greater soil volume, access deep stored or skip row moisture and buffer fluctuations in water availability, reducing reliance on frequent irrigation events and maintaining physiological function under stress (Bange & Constable, 2015).

Root Architecture and Soil Water Extraction

It is useful to distinguish between root depth and root architecture, as both influence the crop's capacity to extract soil water but in different ways. Root depth determines the volume of the soil profile that can potentially be accessed, while root architecture is defined as the spatial configuration of roots including lateral spread, branching density and rooting angle which governs how effectively water and nutrients are extracted from within that volume (Lynch, 2013). In water-limited environments, crops with deeper and more extensively branched root systems are better positioned to access subsoil moisture including in the skip row between irrigation events, providing a buffer against short-term supply deficits and reducing the frequency and volume of irrigation required to sustain productivity.

Soil Type and Plant Available Water Capacity

The value of root exploration is closely linked to the soil's capacity to capture and retain water. Soil type strongly influences plant available water capacity (PAWC), infiltration, drainage characteristics and the distribution of stored moisture within the profile, shaping crop water availability and irrigation strategy. In Australian systems, cotton soils are often characterised as clay soils which provide substantial water storage capacity, enabling crops to access significant subsoil moisture reserves where rooting conditions remain favourable. However, constraints such as compaction, sodicity, poor structural condition or shallow moisture distribution may limit effective root exploration and reduce the crop's capacity to utilise these reserves efficiently. Where such limitations exist, irrigation strategy needs to account for the reduced buffering capacity of the soil profile, with greater emphasis on maintaining adequate water availability in the upper root zone and careful monitoring of soil water status to avoid rapid stress onset.

Early Root Development and Seasonal Water Strategy

Early root development is particularly important, as the depth and distribution of root exploration established during early growth strongly influences the crop's capacity to extract water later in the season (McMichael & Quisenberry, 1993). Cotton exhibits adaptive changes in root growth under moisture stress, often increasing root allocation relative to shoot growth in response to declining water availability (Pace, Cralle, El-

Halawany, Cothren, & Senseman, 1999). Irrigation decisions during establishment and early vegetative growth require a strategic balance of avoiding stress severe enough to restrict root growth, while also preventing excessive early irrigation that may reduce the crop's incentive to develop deeper root systems and access subsoil water reserves later in the season.

In practical terms, early irrigation management is not solely about meeting immediate crop demand, but about shaping the crop's future capacity to tolerate water limitation. A managed deficit during early vegetative growth can encourage deeper rooting and improve the crop's resilience to stress during the more sensitive reproductive stages that follow. This deliberate approach to early season water management represents one of the more important and underutilised strategic levers available to growers in semi-irrigated systems.

Deficit Irrigation as a Strategic Management Tool

This becomes especially relevant in semi-irrigated systems where irrigation capacity is often insufficient to meet full seasonal evapotranspiration demand. In these environments, deficit irrigation is not simply a reactive response to water shortage, but a planned management approach that requires an understanding of crop water extraction patterns, soil water reserves, developmental sensitivity to stress and the timing of yield-critical growth stages. Effective water budgeting including the allocation of available irrigation water across the season in alignment with crop demand curves and stage-specific stress sensitivity is central to this approach. Rather than applying water reactively in response to visible stress, a water budgeting framework enables growers to prioritise irrigation during periods of greatest physiological sensitivity, such as flowering and early boll development, while accepting greater deficit at less critical stages.

Cotton's response to water deficit is highly dependent on growth stage, with stress during flowering and boll development typically resulting in greater yield penalties than transient deficits during vegetative or late boll fill periods (Pettigrew, 2004) (DeTar, 2008). A crop with strong root development and access to stored subsoil moisture may tolerate short-term deficits with limited yield penalty, whereas poorly developed or shallow-rooted crops are more vulnerable to rapid stress onset, reduced fruit retention and compromised boll number. Operationally this requires reliable information on soil water status throughout the profile, so soil moisture monitoring tools including moisture probes and plant-based stress indicators provide the data needed to make informed, timely irrigation decisions and to track whether water is being extracted from the zones of the profile where roots are active. In this way, root zone monitoring bridges the gap between physiological understanding and practical irrigation management, enabling growers to implement deficit strategies with greater confidence and precision.

Yield sensitivity to stress timing

The impact of water deficit on cotton yield is not uniform across the growing season but is strongly governed by the timing and duration of stress relative to reproductive development. Cotton is sensitive to water deficit at all growth stages, but the period from first square through to peak bloom represents the most critical window for yield determination (Loka & Oosterhuis, 2012) (Constable & Hearn, Irrigation for crops in a sub-humid environment, 1981). During this phase, the crop is simultaneously initiating fruiting sites, sustaining flowering and developing early bolls, processes that are highly vulnerable to disruption in assimilate supply and hormonal balance.

The consequences of stress during key reproductive stages have been well quantified. Water depletion during flowering, squaring and boll opening has been shown to reduce yield by approximately 38.8%, 27.9% and 7.6% respectively, highlighting the disproportionate sensitivity of the flowering period relative to later stages (Wang, et al., 2023). Wang et al 2017 At the boll level, the first fourteen days following anthesis represent a particularly critical period; water stress occurring within this window frequently triggers abscission of young bolls, whereas bolls that survive beyond this stage are generally retained (McMichael, Jordan, & Powell, 1973). This narrow window of vulnerability underscores the importance of maintaining adequate soil water availability during early boll development, where even a short-term stress event can translate into a permanent reduction in boll number.

Stress timing also interacts with canopy position to influence the distribution of yield loss across the plant. (Herritt, Thompson, & Thorp, 2022) found that reduced irrigation led to lower boll numbers primarily in the middle-lower canopy quarters, reflecting the preferential retention of bolls at higher fruiting positions under assimilate limitation. This spatial pattern of boll loss has implications for how yield penalties are expressed and reinforces the importance of irrigation scheduling that avoids severe deficit during the period when lower canopy fruiting sites are being established and consolidated.

Beyond boll number, the timing of stress also affects fibre quality. Water stress during the first third of boll filling, when fibres are actively elongating, reduces fibre length, while stress during the latter stages of boll fill reduces fibre maturity and micronaire (Bange, et al., 2018). In semi-irrigated systems where full crop demand cannot always be met, understanding these stage-specific thresholds enables more strategic allocation of limited water to the periods of greatest physiological sensitivity.

Water budgeting in semi-irrigated cotton systems

In water-limited conditions, water budgeting is a critical decision-making tool influencing crop performance, WUE and production risk. Semi-irrigated systems require deliberate allocation of finite water resources to align supply with crop demand, yield targets and seasonal risk (Hearn A. , 1980) (Pettigrew, 2004). This shifts irrigation management from reactive scheduling, by responding to visible crop stress or soil moisture depletion, to proactive strategic planning that anticipates crop demand and allocates water accordingly across the season.

Assessing Total Water Supply

Effective water budgeting begins with a realistic assessment of total water available to the crop across multiple sources: stored soil moisture, confirmed water allocations, on farm storage, expected in-crop rainfall and the operational capacity of the irrigation system to deliver water when and where it is required. Each of these components carries uncertainty, and the interaction between them shapes both the risk profile and the strategic options available to the grower.

In Australian cotton systems, particularly on deep cracking clay soils with high plant available water capacity, stored soil moisture can represent a substantial proportion of total seasonal crop water supply. This makes fallow efficiency and pre-season moisture conservation critical determinants of system performance. A crop entering the season with a full or near-full soil profile has considerably greater flexibility in managing in-season water allocation than one beginning with a depleted profile (Roth, Harris, Gillies, Montgomery, & Wigginton, 2013). Decision support tools such as HydroLOGIC were developed specifically to assist Australian cotton growers in integrating these multiple water supply components into a coherent seasonal water plan (Hearn A. , 1994). There is currently a joint venture project between Cotton Seed Distributors (CSD), CRDC and Goanna Ag called IrrigationIQ. This tool will integrate your water account, storage and linked field sensors enabling more informed trade-offs between crop demand, irrigation capacity and risk management (Cotton Seed Distributors, 2026).

Water Budgeting Across Scales

Water budgeting operates at multiple scales simultaneously from the individual irrigation event, through to seasonal crop management, and ultimately to whole-farm planning. At the field scale, decisions around irrigation timing and volume aim to align water supply with the crop's physiological demand curve and minimise stress during yield-critical growth stages. At the farm scale, decisions around planted area, planting configuration, variety selection and target yield should reflect realistic water supply and delivery capacity. In water-constrained environments, reducing planted area or aligning crop area more closely with available water can improve whole-farm WUE and reduce exposure to the compounding risk of water shortage during peak demand periods (Howell, 2001) (Fereres & Soriano, 2007). The principle is consistent across scales, matching ambition to resource availability improves both productivity and resilience.

Water Budgeting as a Strategic Framework

Ultimately, effective water budgeting integrates the physiological understanding developed throughout this section into a management framework. As climatic variability increases and water resources become more constrained, the capacity of cotton production systems to maintain productivity and profitability will depend not simply on water availability, but on how effectively that water is allocated across the season to protect yield-critical physiological processes, maximise harvest index and sustain water productivity under variable and limiting conditions (ABARES, 2023).

Breeding traits and their role in water-limited cotton systems

While agronomic management plays a significant role in shaping crop response to limited water, inherent varietal characteristics also influence the capacity of cotton to maintain productivity under constrained water availability. In semi-irrigated systems, where irrigation capacity is often insufficient to meet full crop demand, cultivar selection becomes an important strategic decision, influencing crop development, stress response, fruiting dynamics and the stability of both yield and fibre quality. Breeding has historically prioritised improvements in yield potential, pest resistance and fibre quality; however, increasing climatic variability and tighter water constraints are placing greater emphasis on traits that improve adaptation to water-limited environments (Bange & Constable, 2015).

Determinacy and the Vegetative–Reproductive Trade-off

One trait of particular interest in semi-irrigated systems is determinacy, which describes the extent to which a crop commits to reproductive development relative to continued vegetative growth. Cotton is an indeterminate crop, with vegetative growth continuing alongside flowering and boll development over an extended period (Bange & Constable, 2015) (Bange & Milroy, 2004). This provides flexibility to compensate following transient stress through continued fruiting, which can be advantageous in environments where water availability supports prolonged growth. In water-limited systems, however, this same characteristic can increase production risk. Continued vegetative growth extends transpiration demand, delays maturity and increases reliance on late-season water availability- a constraint that becomes particularly acute when seasonal allocations are finite or uncertain.

Greater determinacy, characterised by earlier fruit set, more concentrated boll accumulation and a shorter effective reproductive window, may offer advantages in semi-irrigated systems by improving alignment between crop water demand and available resources and by reducing the risk of late-season water deficit coinciding with active reproductive growth. Conversely, greater determinacy may limit the crop's capacity to compensate following stress events or respond positively to improved seasonal conditions, a meaningful trade-off in environments with high rainfall variability (Bange & Constable, 2015). It is important to note, however, that current Australian cotton varieties sit along a spectrum of determinacy rather than being classified as strictly determinate or indeterminate and the practical expression of these traits is strongly influenced by management, environment and seasonal conditions.

Boll Accumulation and Reproductive Efficiency

Closely linked to determinacy is boll accumulation, which strongly influences how effectively the crop converts available water and assimilates into harvestable yield. Cotton yield is primarily determined by boll number, making fruit retention and reproductive efficiency particularly important under water-limited conditions (Oosterhuis, 1999) (Pettigrew, 2004). The ability to set and retain early fruit during periods of favourable water availability may be advantageous in semi-irrigated systems, reducing reliance on prolonged vegetative growth and late-season compensation. Varieties with strong early boll retention and efficient assimilate partitioning toward reproductive structures may therefore achieve higher harvest indices under water limitation, converting a greater proportion of total biomass into lint yield.

However, concentrated reproductive demand associated with more determinate fruiting patterns may also increase vulnerability where assimilate supply or water availability becomes limiting during critical developmental windows. The synchrony between boll load and crop water demand is an important varietal characteristic. Cultivars that distribute fruiting load across a period that aligns well with water supply may offer more consistent performance across seasons (Bange & Constable, 2015).

Fibre Quality Stability Under Stress

Beyond yield, the stability of fibre quality attributes under stress is increasingly important in the commercial context of semi-irrigated cotton production. Water deficit and heat stress during flowering and fibre development can alter fibre length, strength, micronaire and uniformity, affecting both crop value and marketability (Snider, Oosterhuis, Skulman, & Kawakami, 2009). The economic consequences of quality deterioration under stress can be substantial, as discounts applied to off-specification fibre can significantly erode the returns from an otherwise adequate yield.

Varietal differences in the capacity to maintain fibre quality under stress are well documented, and quality stability is an increasingly important selection criterion alongside yield performance. Varieties that combine competitive yield potential with robust fibre quality stability under water deficit and heat stress are particularly well suited to semi-irrigated and rainfed production systems, where stress during fibre development cannot always be avoided through irrigation. As water constraints tighten and seasonal variability increases, the economic value of quality stability not just yield stability will become an increasingly important consideration in cultivar selection decisions (Constable & Bange, 2015).

Transpiration Efficiency as a Breeding Target

Given that the central challenge of semi-irrigated production is converting limited water into maximum yield, transpiration efficiency (TE) can be explored to maximise lint produced per unit of water transpired. Genotypic variation in TE has been documented in cotton (Condon, Richards, Rebetzke, & Farquhar, 2004). Varieties with inherently higher TE are better positioned to sustain productivity as water availability declines, without requiring additional agronomic intervention to moderate crop water use. Additionally, the capacity for osmotic adjustment is documented as the ability of plant cells to maintain turgor and physiological function under declining water potential. Osmotic adjustment is a heritable trait that contributes to stress tolerance, enabling continued stomatal function, photosynthesis and reproductive development under conditions that would otherwise trigger rapid stress responses (Turner, Hearn, Begg, & Constable, 1986). Similarly, root vigour, including the rate and depth of early root development has a genetic component and influences the crop's capacity to access stored subsoil moisture, as discussed in earlier sections. These physiological traits collectively represent an important dimension of varietal adaptation that complements agronomic management in water-limited systems.

Appendix 2.2: Extended Systems Research

Systems based approach

Where plant management focuses on how efficiently the crop uses available water, farming systems management focuses on how effectively that water is captured, stored and delivered to the crop. In semi-irrigated cotton systems, the production environment surrounding the crop matters as much as the crop itself: system design shapes not only water availability, but risk exposure, operational flexibility and the consistency with which production opportunities convert into profitable outcomes.

A farming systems approach recognises that farm performance is shaped by the interaction between multiple system components, strategic choices and external influences over time, not by isolated management decisions (Thyer, 2025). Rather than focusing on single-season outcomes, systems thinking considers how management decisions affect long-term profitability, sustainability and resilience. This is particularly relevant in semi-irrigated cotton, where variable water availability demands decisions that balance productivity, risk and resource efficiency.

Farming systems research is often framed around management levers that explain interconnected decisions growers make to optimise system performance. These decisions operate across three dimensions: strategic, tactical and temporal, each influencing the others and collectively determining how well a system responds to the variability. This section examines how decisions across each dimension interact to shape overall system performance in semi-irrigated cotton.

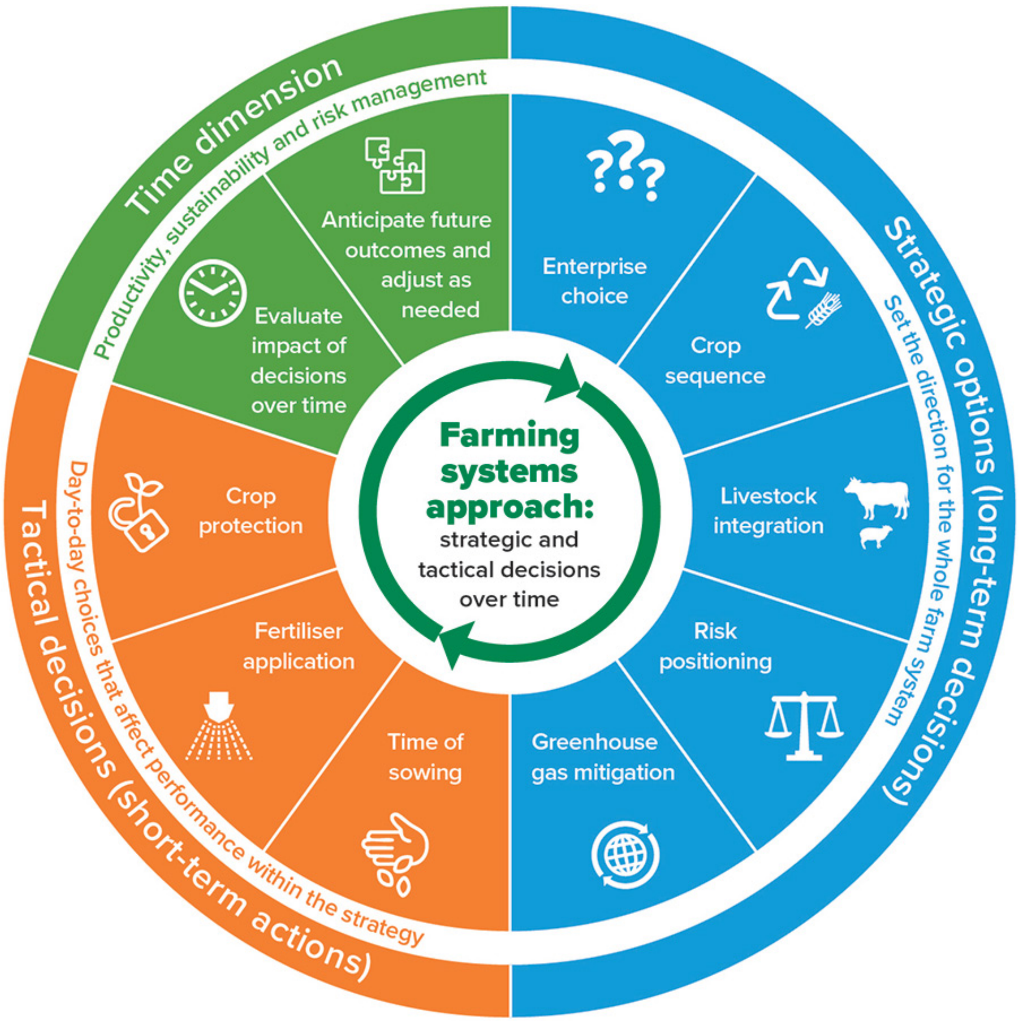


Figure 17: What is farming systems approach? Adapted from Dr. Matthew Knowling, University of Adelaide (Thyer, 2025).

Strategic options: designing systems for water- limited performance

Strategic decisions shape the overall structure, flexibility and risk profile of farming systems, influencing how effectively resources are allocated across variable seasons. Unlike tactical decisions, which focus on in-season execution, strategic choices establish the longer-term framework within which operational decisions are made. In semi-irrigated cotton systems, water availability is inherently uncertain, and production often depends on a combination of stored soil moisture, opportunistic rainfall and limited water allocations. Importantly, semi-irrigated conditions are not uniform in their origin. Some systems operate in this mode permanently due to limitations in water access, while others transition in and out of full production in response to the boom-and-bust cycles that characterise water availability across many Australian cotton regions. In either context, strategic decisions determine both system resilience and the capacity to capitalise on production opportunities when they arise.

Enterprise mix and crop sequencing

Enterprise mix is a foundational strategic decision that shapes the flexibility, resilience and risk profile of a farming business. More diversified systems may distribute climatic and market risk across multiple enterprises, while more specialised systems can offer efficiencies of scale and streamlined operations, though often with greater exposure to production or commodity volatility (Lin, 2011). In cotton-focused farming systems, enterprise selection is largely determined by the biophysical and resource constraints of the production region, meaning the strategically significant decision shifts from which enterprises to run toward how those enterprises are sequenced over time.

Crop sequencing extends well beyond the performance of any individual crop, influencing soil physical condition, water capture and storage, nutrient dynamics, pest and disease pressure, and the operational flexibility of the broader farming system. Diverse rotations have been associated with improved system function through risk diversification, disruption of pest and disease cycles and greater adaptive capacity under climatic variability (Lin, 2011). In semi-irrigated cotton systems, these benefits are amplified because stored soil moisture is a critical production asset and the preceding crop strongly influences both the quantity and accessibility of water available to subsequent crops.

Rotational decisions affect fallow length, residue load, soil cover, root architecture and soil structural condition, all of which influence infiltration, evaporation losses and the efficiency of soil water storage. Sequencing also carries important implications for disease management, particularly where Verticillium wilt, Fusarium wilt and nematode pressure may be influenced by crop choice and rotation frequency. Beyond these biophysical impacts, crop sequencing affects labour distribution, machinery demand and the timing of critical operations, shaping the system's capacity to respond to seasonal opportunities. In this context, rotational design becomes not simply a crop planning exercise, but a strategic mechanism for improving water productivity, reducing risk and enhancing long-term system resilience.

Risk positioning and matching system intensity to water availability

Strategic risk positioning shapes how exposed a farming system is to climatic, financial and operational uncertainty. In semi-irrigated cotton systems, where water availability is inherently variable, growers must make early decisions around crop area, input investment and production ambition with incomplete information about rainfall and irrigation supply. The fundamental challenge is not simply growing cotton with less water but aligning system intensity with realistic resource availability and risk tolerance.

Higher intensity systems may offer greater upside in favourable seasons, but increase exposure when rainfall is unreliable or irrigation availability tightens. More conservative approaches may reduce peak production potential but improve consistency, resilience and financial stability across seasons. In practice, effective risk positioning requires balancing stored soil moisture, seasonal outlook, irrigation availability and risk appetite to determine the appropriate scale of production (Welsh, Taschetto, & Quinn, 2022).

For systems that operate permanently with a semi-irrigated approach due to limitations in water access, this calibration is a constant discipline. For those transitioning in and out of full production across boom-and-bust cycles, the ability to read conditions early and adjust system intensity accordingly is a critical competitive advantage.

In water-limited environments, preserving flexibility and matching ambition to available resources is not a conservative choice, it is a strategic one. The growers who consistently convert production opportunities into profitable outcomes are often those who resist the temptation to overcommit, maintaining the financial and operational headroom to respond when conditions favour a more aggressive approach.

Tactical decisions: short-term actions

Tactical decisions are the shorter-term management actions that influence how effectively a farming system performs within a given season. While strategic decisions establish the broader production framework, tactical decisions determine how efficiently resources are utilised in response to prevailing seasonal conditions. In semi-irrigated cotton systems, where production outcomes are strongly influenced by rainfall timing, irrigation constraints and operational execution, these decisions convert available water into profitable outcomes. Tactical management therefore becomes the interface between system design and seasonal reality, shaping both water use efficiency and crop resilience.

Controlled Traffic Farming and operational efficiency

Controlled traffic farming (CTF) confines machinery movement to permanent, designated traffic lanes, eliminating uncontrolled compaction across the production area and preserving soil structure within the crop zone. By protecting pore continuity, infiltration capacity and root exploration, CTF improves the soil's ability to capture, store and supply water for crop use, making it particularly relevant in semi-irrigated cotton systems where water is a constrained and variable resource (Tullberg, Yule, & McGarry, 2007). While inherent soil type sets the baseline for water holding capacity, management strongly influences how effectively that capacity is realised, and CTF represents one of the most impactful structural interventions available to growers.

In furrow-irrigated cotton systems, wheel track compaction can significantly reduce infiltration, create spatial variability in water distribution and negatively impact crop establishment where poor physical conditions restrict seedling emergence or early root development. These effects are compounding; degraded soil structure reduces the volume of water stored per millimetre of rainfall or irrigation, increasing reliance on inputs while simultaneously reducing their efficiency. In semi-irrigated systems operating at the margins of viable production, this inefficiency can be the difference between a profitable crop and not.

Beyond soil physical benefits, CTF delivers meaningful operational advantages through greater machinery precision, reduced overlap and improved timeliness of field operations. In systems where seasonal windows are narrow and tactical decisions must be executed rapidly, the ability to move onto country earlier and operate more efficiently can materially influence production outcomes. These advantages extend across rotational crops, improving the practicality of winter cereal and dryland or semi-irrigated cotton sequences by maintaining trafficability and reducing whole-paddock structural degradation between enterprises. For semi-irrigated systems managing the transition between low and high-water availability seasons, the operational flexibility that CTF enables can be as valuable as its soil physical benefits allowing growers to capitalise on production opportunities when conditions allow, without compromising the resource base that underpins long-term system performance.

Crop configuration

Crop configuration is a tactical decision that influences how efficiently available water is converted into productive crop growth. Choices around row spacing and arrangement, plant population and crop intensity directly affect canopy development, root competition, soil water extraction and evaporative losses making configuration an important management lever in semi-irrigated cotton systems. Unlike fully irrigated systems, where design is largely optimised around maximising yield potential, semi-irrigated systems require a more adaptive approach, with production intensity matched to realistic water availability and seasonal conditions.

Row configuration options, ranging from solid plant through to skip arrangements, represent fundamentally different trade-offs between yield potential, crop water demand and risk exposure. Solid plant systems maximise canopy closure and yield potential but carry the highest water demand, making them best suited to seasons where soil moisture and irrigation supply are sufficient to support the crop through to cutout. Single skip configurations or 60 inch solid (66% green area) reduce plant population and water demand while retaining reasonable yield potential, offering a practical middle ground in seasons of moderate water availability. Double skip systems or 2m solid (50% green area) reduce crop intensity further, lowering water demand and improving the likelihood of completing the crop within available resources, but at a significant cost to yield ceiling. In semi-irrigated systems where the consequences of running out of water mid-season are severe both agronomically and financially the ability to select a configuration that matches crop demand to realistic supply is a critical risk management tool.

Where machinery configuration and CTF wheel spacing constrain flexibility in row arrangement, plant population becomes an additional tactical lever. Adjusting seeding rate allows growers to modify crop intensity and water demand without altering infrastructure or machinery compatibility, providing meaningful flexibility within a fixed physical system. Configuration decisions also interact with planting date, irrigation strategy, soil moisture distribution and seasonal outlook, reinforcing their role as a dynamic risk management tool rather than a fixed production setting, maximising the probability of a profitable crop, not simply maximising yield potential.

Reduced tillage, stubble retention and cover cropping

Reduced tillage, stubble retention and residue management are tactical decisions that influence how effectively rainfall and irrigation are captured, conserved and made available for crop use. By minimising soil disturbance and maintaining surface cover, these practices can improve infiltration, reduce evaporation losses, protect soil structure and support more efficient storage of plant available water. In semi-irrigated cotton systems, where production relies on a combination of stored soil moisture, opportunistic rainfall and supplementary irrigation, improving the efficiency of water capture between and within seasons can have a meaningful impact on both productivity and resilience.

Surface residue plays a particularly important role in moderating the soil microclimate, reducing direct evaporative losses and protecting against surface sealing and structural decline following rainfall or irrigation events. In mixed farming systems, cereal stubbles can provide valuable soil cover that supports moisture conservation and improved infiltration ahead of subsequent cotton crops. In some furrow-irrigated systems, transitioning production onto flat land rather than maintaining configurations designed primarily for rapid irrigation water movement can improve rainfall capture and in-field water storage, increasing the productive value of opportunistic rainfall events that are central to semi-irrigated production.

Cover cropping represents an emerging extension of these principles, using living or terminated plant cover during fallow periods to actively build soil function rather than simply conserving existing condition. Well-managed cover crops can improve soil organic matter, enhance biological activity, increase aggregate stability and improve infiltration, collectively contributing to greater water holding capacity and more efficient soil water storage over time. In semi-irrigated systems, where fallow periods between crops are common and soil water storage is a critical production asset, cover cropping offers a pathway to progressively improving the productive capacity of the soil resource. However, cover crop water use during the fallow period must be carefully managed, particularly in water-limited environments where the risk of depleting stored soil moisture ahead of the cotton crop can outweigh the longer-term soil health benefits. Effective integration therefore requires careful species selection, termination timing and monitoring of soil moisture to ensure fallow water storage is not compromised.

Residue management and reduced tillage must be balanced against operational considerations, including establishment challenges, pest and disease dynamics and machinery compatibility. These practices collectively represent an important tactical pathway to improving water productivity in semi-irrigated cotton systems. Their value lies not only in individual season performance but in their cumulative contribution to soil function, system resilience and long-term productive capacity.

Time of sowing and in-season flexibility

Sowing date is one of the most consequential tactical decisions in semi-irrigated cotton production, influencing the crop's heat unit accumulation, its alignment with seasonal conditions and the likelihood of completing the crop within available water resources. In fully irrigated systems, sowing decisions are driven primarily by agronomic optimisation. In semi-irrigated systems, the optimal sowing window is not fixed. It is determined by the interaction between soil moisture profile, seasonal forecast, irrigation availability and the grower's risk tolerance in that season.

In water-limited systems, that variability creates opportunity. Sowing later in the planting window deliberately shifts the crop's peak water demand later in the season, aligning boll development and boll fill with cooler temperatures and lower evaporative demand (Anwar, Wang, Liu, & Waters, 2020). This improves the efficiency with which limited water resources are converted into yield. Where irrigation allocations are tight or stored soil moisture is insufficient to support a full-season crop, this approach can meaningfully improve the probability of finishing a crop. When combined with reduced intensity configurations such as skip-row planting, later sowing becomes an option that accepts a lower yield ceiling in exchange for greater certainty of outcome and more efficient use of constrained water supplies.

Operational readiness is a critical and often underappreciated component of sowing flexibility. The ability to respond rapidly to a sowing opportunity is paramount, be it triggered by a rainfall event, a favourable forecast or an unforeseen pumping opportunity. In semi-irrigated systems, where sowing opportunities may be narrow and optimum conditions can deteriorate quickly, growers who are consistently positioned to act gain a meaningful production advantage over those constrained by operational or logistical delays.

In-season flexibility extends beyond sowing decisions to encompass the ongoing management of crop water demand, irrigation scheduling and crop growth management. As the season develops, growers must continuously reassess the alignment between crop water demand and available supply in response to changing conditions. Where water availability tightens mid-season, the decision to reduce irrigations, advance cutout or accept a lower yield ceiling in favour of completing the crop within available resources can be more profitable than persisting with a crop that will not finish. In semi-irrigated systems, the capacity to make these in-season adjustments efficiently is the hallmark of well-designed, resilient farming systems and a critical link between tactical decision-making and the strategic risk positioning established at the outset of the season.

Adaptive Management and long-term system performance

Strategic and tactical decisions do not operate in isolation; their true value is revealed through their cumulative effect on system performance over time. Management decisions made today shape the resource base, operational capacity and risk profile of the system in future seasons. In semi-irrigated cotton systems, where seasons of high-water availability may be separated by extended periods of constraint, the ability to maintain system function and productive capacity across the full cycle is as important as performance in any individual season.

Multi-season thinking requires growers to evaluate decisions not only on their immediate return but on their longer-term implications. Practices that improve soil structure, water holding capacity and biological activity such as CTF, reduced tillage, residue retention and cover cropping may deliver modest returns in any single season but compound significantly over time, progressively improving the system's ability to capture, store and utilise water. Similarly, conservative risk positioning in constrained seasons preserves the financial and operational headroom that allows growers to take on a more aggressive approach when the season allows. The accumulation of these decisions across seasons is what separates systems that perform consistently from those that excel in good years but struggle to recover from difficult ones.

Adaptive management is central to navigating variable seasons. Rather than applying fixed management rules across all seasons, high-performing systems are characterised by the capacity to learn from outcomes, adjust strategies in response to new information and continuously refine the alignment between system design and production environment. In semi-irrigated cotton systems, examples of this may include revisiting crop rotation decisions in response to disease pressure or adjusting cropping intensity as water entitlements evolve. The willingness to evaluate decisions critically and adjust accordingly is a defining characteristic of resilient, adaptive farming systems.

Ultimately, a systems perspective reframes how performance is measured. Rather than assessing success solely through single-season outcomes it evaluates performance through the lens of consistency, resilience and the long-term return on asset managed. In semi-irrigated cotton systems navigating the inherent variability of water-limited environments, this longer-term view is the foundation upon which sustainable, profitable production is built. Growers who manage strategically and tactically with one eye on the season ahead and another on the decade ahead are those best positioned to convert the variability of semi-irrigated production into a consistent and competitive advantage.

What does that mean in practice?

There is significant complexity to irrigated farming systems, especially those performing under constraint. System design directly influences productivity, risk exposure, adaptability and the likelihood of converting opportunities into profitable outcomes. In Australian cotton regions, water availability is rarely static, some systems operate permanently under constraint while others cycle between periods of full production and reduced capacity in response to the boom-and-bust nature of water availability across many catchments. As access to water becomes more variable and competition for this resource intensifies, the ability to generate profitable returns across a wider range of seasonal conditions will become an increasingly important measure of performance.

Through extensive research the key management principles that underpin successful semi-irrigated cotton crops and that distinguish those who consistently convert opportunity into profit are as follows:

Plant into retained stubble under reduced tillage
Plant residues and reduced surface disturbance protects soil structure, moderates evaporative losses and improves water capture during fallow periods. It is driving the capacity to perform under constraint and increases planting opportunities for semi-irrigated growers.

Build and protect fallow moisture
Planting into substantial stored soil moisture preserves allocation for the periods of highest demand during flowering and boll development. The distinction between planting into moisture and watering up is not simply a tactical preference; in constrained systems it directly influences establishment, early root development and the volume of water available to the crop to build yield.

Match configuration and planting date to available water
Row configuration and plant population determine the crop's water demand before the season begins. Used together with planting date, these decisions are the most accessible risk management levers available to semi-irrigated growers. By shifting peak demand into cooler, lower evaporative demand conditions you are improving the probability of completing a profitable crop given the available resources.

Invest in soil health and long-term nutrition
Treating soil as an asset that prioritises soil health and fertility ensures a resilient system that maintains function under constraint. A long-term strategy that considers crop rotation, residues and soil biology is as much a water productivity decision as an agronomic one.

Prioritise timeliness of operations
In semi-irrigated systems, where sowing windows are narrow and conditions can shift quickly, the ability to execute critical operations at the right time is a genuine competitive advantage. Operational readiness is a system design requirement, not simply good management practice. The opportunity cost is too great to compromise.

Critically analyse and benchmark performance
Understanding what is driving performance, is the cornerstone to profitability over time. Benchmarking can be undertaken internally by tracking key metrics such as water use efficiency, cost of production and return on assets across seasons, or externally through specialist services. AgriPath, a well-respected benchmarking company servicing the Australian Cotton Industry show that the top performing farms achieve this through attention to timing and detail with a focus on forward thinking (Agripath Pty. Ltd. , 2024). In variable environments, the discipline of measuring what matters and acting on it is what separates systems that continually improve from ones that don’t.

Appendix 2.3: Extended Data and Technology Research

Digital Agriculture: The value of technology and data

Technological innovation has long underpinned agricultural progress, driving gains in productivity, efficiency and system resilience. This has been realised through advances in mechanisation, genetics, infrastructure and precision management. As agricultural systems face increasing pressure from climate variability, rising input costs and resource constraints, the role of technology is evolving from simply improving operational efficiency to enabling more informed, adaptive decision-making. This evolution reflects a broader transition from precision agriculture, focused primarily on improving the accuracy and efficiency of farm operations, toward digital and decision agriculture, where interconnected technologies, data systems and analytics support more informed management decisions (Perrett, Heath, Laurie, & Darragh, 2017).

In semi-irrigated cotton systems, water management decisions extend beyond operational precision and into strategic resource allocation. Unlike fully irrigated systems, where water can more consistently be applied to meet crop demand, semi-irrigated production requires growers to make deliberate decisions about how limited water resources are allocated across changing seasonal conditions, soil water, crop demand and operational constraints. The greatest value of technology lies not in its technical capability alone, but in its capacity to improve decision making, resource efficiency and operational execution. In practice, the effectiveness of these technologies depends on their accessibility, integration into existing systems, and the confidence of growers and advisors to interpret and act on the information generated.

The value of technology can be considered across three functional roles:

- Monitoring to improve visibility across the production system
- Decision support to convert information into action
- Operational execution to turn decisions into outcomes

Together, these functions influence the capacity of growers to respond with greater precision and adaptability in water-limited production environments.

Monitoring: improving visibility

Effective decision-making in semi-irrigated cotton systems depends on an accurate understanding of both resource availability and crop response. In water-limited environments, uncertainty around stored soil moisture, plant water status, atmospheric demand and irrigation system performance can significantly influence both tactical and strategic management decisions. Technologies that improve visibility across the production system reduce this uncertainty, enabling earlier intervention, more informed irrigation scheduling and greater confidence in allocation decisions.

Understanding available water is fundamental to irrigation decision-making. Capacitance probes, often integrated with telemetry platforms, provide real-time insight into soil water dynamics, enabling growers and advisors to track water extraction through the profile, monitor irrigation refill and identify emerging deficits before visible crop stress occurs. Patterns of extraction through the profile can also improve understanding of rooting depth and where the crop is drawing moisture, which is particularly valuable when determining first irrigation timing and irrigation timing following rainfall events. However, fixed-point monitoring tools represent only a small snapshot of the production environment, and their value depends heavily on appropriate placement, calibration and an understanding of soil variability. Complementary technologies such as electromagnetic (EM) surveys provide a broader spatial understanding of soil characteristics, WHC and moisture distribution, improving both the interpretation of point-based monitoring and confidence in water budgeting decisions. When integrated with farm-scale water accounting frameworks, such as the Water Dashboard project (IrrigationIQ), currently being undertaken in partnership between Goanna Ag, Cotton Seed Distributors (CSD) and the Cotton Research and Development Corporation (CRDC) these technologies support more informed and disciplined irrigation planning by providing growers with a real-time understanding of total water availability across the enterprise.

While soil and water monitoring improve understanding of resource availability, they do not necessarily reflect the crop's physiological experience. Root distribution, soil constraints, atmospheric demand and fruit load can all influence plant water status independently of measured soil moisture. Canopy temperature sensors (CTS) address this gap, providing a more direct measure of crop water stress based on the principle that stomatal closure under water deficit reduces transpirational cooling and increases canopy temperature relative to ambient conditions. Fixed in-field sensors are the most common deployment in Australian cotton systems, though UAV platforms and thermal imagery are emerging as valuable tools for identifying spatial stress patterns across fields and supporting more targeted management responses. Physiological indicators such as growth rate and nodes above white flower (NAWF) provide additional insight into crop stress, fruit retention and changes in plant growth dynamics under limited water conditions, complementing soil-based monitoring with a more direct assessment of crop response.

Environmental monitoring technologies complete the picture by improving understanding of atmospheric conditions influencing crop water use and irrigation demand. On-farm weather stations provide real-time measurements of temperature, humidity, rainfall, wind and solar radiation, supporting irrigation scheduling, spray timing and heat stress assessment during critical growth periods. Evapotranspiration tools use these data streams to estimate crop water use and atmospheric demand, and when integrated with soil and plant monitoring, improve understanding of the relationship between crop demand and available water. Weather forecasting tools further strengthen this picture, improving the ability to anticipate weather events and changing evaporative demand and enabling more proactive and adaptive management across the season.

Spatial monitoring technologies provide a further layer of visibility by improving understanding of variability across the production environment. Satellite imagery and multispectral imaging offer field-scale insight into crop growth, canopy development and plant health throughout the season. Vegetation indices such as NDVI and PCD imagery assist in identifying variation in crop vigour, biomass accumulation and stress response, supporting targeted management decisions like variable rate growth regulation. When integrated with soil moisture monitoring, EM mapping and yield data, spatial technologies improve understanding of how soil variability, water availability and crop performance interact across the system, supporting both in-season management and longer-term planning decisions.

Decision support: converting information into action

The value of monitoring technologies lies not in the collection of data alone, but in their capacity to improve the quality and confidence of management decisions. In semi-irrigated cotton systems, where water availability, seasonal conditions and production risk are highly variable, the challenge is no longer simply accessing data but interpreting it effectively and translating it into timely actions. Decision-support technologies aim to bridge this gap, converting complex and dynamic datasets into insights that improve the precision, consistency and adaptability of farm management.

At a tactical level, irrigation scheduling platforms integrate soil moisture monitoring, crop stress indicators, evapotranspiration models and weather forecasting to better align irrigation timing and volume with crop demand. Rather than relying on fixed scheduling intervals or single-point observations, these platforms draw on multiple data streams to build a more complete picture of crop water status and system performance. Commercial platforms, such as those offered by Goanna Ag are increasingly being adopted across Australian cotton systems and globally, providing growers and advisors with accessible, integrated views of soil, water and environmental data that support more responsive in-season management. The effectiveness of these tools depends not only on data quality and sensor placement, but on the confidence of growers and advisors to interpret outputs and act on them within the constraints of their specific production environment.

At a strategic level, the most effective decision support is often not a platform but a person. Agronomists, business advisors and benchmarking professionals who understand both the production environment and the financial realities of a farming business are uniquely positioned to translate data into strategic recommendations. Where monitoring technologies improve visibility and decision-support platforms improve access to information, trusted advisors improve the quality of the questions being asked. They can help growers evaluate crop choice, input investment, water allocation and production ambition against a clear understanding of risk, capacity and long-term business objectives. In semi-irrigated cotton systems, where early season decisions carry significant financial consequences and are made with incomplete information, the combination of good data and experienced strategic counsel is what most consistently converts information into sound long-term decisions.

Predictive analytics and modelling platforms extend this capability further, improving the ability to forecast crop performance, irrigation demand and yield potential under variable seasonal conditions. By integrating historical production data with real-time monitoring, these systems identify patterns and support more proactive management. In water-limited systems, where overcommitting inputs under constrained water availability increases financial risk, improved forecasting of yield potential supports better alignment between production ambition and realistic resource availability, improving both resource use efficiency and profitability.

Retrospective analytics play an equally important role in supporting adaptive management and long-term system improvement. The integration of datasets including yield maps, irrigation records, spatial imagery and physiological observations allows growers and advisors to evaluate the interaction between water availability, crop response and management decisions across seasons. This retrospective lens can identify recurring constraints associated with soil variability, irrigation performance or management practices, informing more targeted decisions in subsequent seasons. In semi-irrigated systems, analytics may also improve understanding of the relationship between water input, yield response and profitability, helping identify where additional irrigation or management intensity generates diminishing returns and where resources are most productively allocated.

Emerging artificial intelligence technologies may further expand decision-support capability through improved pattern recognition and automation. While current applications in cotton systems remain limited, the longer-term potential to integrate multiple layers of production data into real-time recommendations is significant. In the near term, the more immediate opportunity lies in improving how existing data is interpreted and acted upon, ensuring that the information already being collected is translated into consistent, confident management decisions.

Ultimately, the effectiveness of decision-support technologies depends on their ability to simplify complexity rather than add to it. Tools that are accessible, well-integrated into existing farm management systems and supported by capable advisors are those most likely to improve decision quality in practice. In semi-irrigated cotton systems, where the margin between a profitable crop and a missed opportunity can be measured in days, the capacity to make better decisions faster and with greater confidence is a genuine competitive advantage.

Operational execution: turning decisions into outcomes

The value of monitoring and decision-support technologies is ultimately realised at the point of execution. In semi-irrigated cotton systems, where irrigation timing, water delivery and operational responsiveness can materially influence crop performance and WUE, the capacity to translate decisions into timely and effective management actions is as important as the quality of the decisions themselves. Technology plays a critical role in this translation. Labour availability and operational capacity are persistent constraints in Australian cotton farming systems. During critical periods like first irrigation, peak water demand and picking, the simultaneous pressure of multiple time-sensitive operations can limit the ability to respond as precisely and promptly as decisions and conditions demand. Automation technologies, including remote pump start-stop systems, automated bay and gate control and telemetry-enabled irrigation management, directly address this constraint by reducing reliance on manual intervention. The ability to monitor and manage irrigation remotely, adjusting timing, volume and delivery in response to changing conditions without requiring physical presence in the field improves both the precision of water application and the operational flexibility of the farming system.

This operational flexibility is particularly valuable in semi-irrigated systems, where the window between a sowing opportunity and deteriorating conditions, or between a stress signal and an irrigation response, can be narrow. The same timeliness principles that underpin success in the broader farming system apply equally to irrigation management. Automation extends the operational reach of the grower and advisor, improving the capacity to act decisively across multiple fields and operations simultaneously without the constraints of logistics dictating the timing of critical decisions.

Water delivery monitoring systems, including dam and channel level sensors, flow monitoring and telemetry-enabled infrastructure, improve visibility of water movement throughout the irrigation system. These technologies support more accurate water accounting, assist in identifying delivery inefficiencies and improve confidence in irrigation application volumes, all of which contribute to more disciplined and informed water use in constrained systems. When integrated with farm-scale water accounting platforms, delivery monitoring can further strengthen the connection between what is planned and what is applied, closing the loop between decision support and operational outcome.

Infrastructure design ultimately determines the ceiling of what operational technologies can deliver. Automation-enabled layouts, bankless channel systems and irrigation infrastructure designed for efficient water movement improve the practical implementation of irrigation decisions at farm scale. In systems where infrastructure constraints limit the speed or precision of water delivery, the value of monitoring and decision-support technologies is inherently capped. The best decision poorly executed still results in a suboptimal outcome. Investing in infrastructure that enables technology to function as designed is therefore as much a productivity decision as the technology itself.

Together, monitoring, decision-support and operational execution technologies are reshaping how irrigated cotton systems are managed. Their value lies not in any single tool or platform, but in their integration and the capacity to move from data visibility, through informed decision-making, to precise and timely execution. In semi-irrigated cotton systems, where the margin between a profitable season and a missed opportunity is often narrow, this integration is what determines whether technology delivers on its potential. The challenge for growers and advisors is not access to technology, it is building confidence, capability and systems to use it well.

Appendix 2.4: Extended Policy Research

Policy: the framework behind farm performance

Improving water use efficiency within semi-irrigated cotton systems does not occur in isolation from the broader institutional environment. Water policy, allocation frameworks and regulatory settings play a significant role in determining the value of water, the level of supply certainty and the incentives for improving efficiency within production systems. The decisions growers make about how water is allocated, invested in and managed are shaped as much by the policy environment as by the agronomic and economic conditions of their farming system. Where policy creates security, clarity and appropriate incentives, growers invest with confidence, adopt technology and build more resilient systems.

Water governance frameworks are the institutional, legal and regulatory structures that determine how water is allocated between environmental, urban and agricultural users. How these frameworks are designed influences not only water availability but the certainty, flexibility and long-term security with which growers can plan, invest and adapt. In regions where water is increasingly contested, the quality of governance determines whether agricultural systems can respond to variability with confidence or continue to be constrained by uncertainty.

Increasingly, these policy settings are intersecting with sustainability frameworks, environmental reporting requirements and market-driven expectations around traceability and responsible resource use. International policy developments, such as the European Union's Green Deal, are further influencing agricultural production systems and fibre supply chains through evolving environmental standards and reporting obligations. This chapter explores the influence of water policy on production systems, examines country-level case studies across Australia, the US and Brazil, and considers the growing role of sustainability frameworks, ESG reporting and supply-chain traceability in shaping how water efficiency is valued and measured within the cotton industry.

The value of water and its influence on decision-making

Water in irrigated agricultural systems is both a production input and an economic asset. How it is priced, allocated and traded determines not only how much water growers have access to, but how they value it, how efficiently they use it and how confidently they invest in the infrastructure and management systems that improve its productive use. Where water has a clear and transparent market value, as it does in Australia's Murray-Darling Basin through the water entitlement trading system, growers are incentivised to use it as efficiently as possible, because every megalitre has a measurable cost. Where water is effectively unpriced or allocated without clear security of tenure, that incentive is weakened and the incentive to invest in efficiency is reduced.

Allocation security is equally important. Growers who cannot reliably predict their water availability from season to season face a fundamentally different investment calculus than those operating within a secure and well-defined entitlement framework. Long-term investments in infrastructure, technology and system design that improve water use efficiency over time require confidence that the resource will be available to generate a return. Uncertainty around allocation, whether driven by policy reform, environmental water recovery or climate variability, creates a risk environment that can suppress exactly the investment behaviour that efficient water use depends upon.

The value growers place on water also directly influences crop choice, system intensity and production ambition. As water becomes more scarce and more expensive, the economic pressure to maximise return intensifies, shifting the focus from bales/ha toward the metric that matters most in water constrained systems- return/ML. This is not simply an agronomic shift; it is a fundamental reorientation of how farming businesses are managed and evaluated.

Water policy in practise: Global Insights

AUSTRALIA

Australia's Murray-Darling Basin (MDB) represents one of the most sophisticated water governance frameworks in the world and remains one of the most contested. The Murray Darling Basin Plan (MDBP), established under the Water Act 2007, sought to balance agricultural, environmental and urban water needs through a cap on consumptive use and a program of environmental water recovery. The water entitlement trading system that underpins the Basin has created genuine price signals that incentivise efficiency. Temporary water prices in the southern Basin have at times exceeded $500/ML, fundamentally changing how growers value, allocate and manage water at a farm level. At that price, every irrigation decision carries real economic consequence and the incentive to improve efficiency is not simply agronomic, it is financial.

However, the ongoing program of water buybacks and the progressive reduction in water available to agriculture has created significant volatility for irrigated farming communities. Reduced overall volumes have driven efficiency gains, but at a social and economic cost to regional communities. 1 in 3 litres of irrigation water has been recovered from agricultural production for the environment, meaning 72% of average river flows in the Basin are now held for environmental purposes and just 28% remains available to water users; a fundamental shift in the productive water base of the Basin (National Irrigators Council, 2025).

The MDBP is currently under review, reflecting the ongoing tension between environmental water recovery targets and the productive and social needs of agricultural regions. The challenge is further compounded by climate.

The CSIRO Murray-Darling Basin Sustainable Yields 2025 report projects that:

- The MDB is virtually certain to be hotter, and annual rainfall is likely to become more variable
- Runoff and water availability are very likely to decline, particularly in the south
- Longterm average annual flows are projected to decline
- Droughts will become more frequent, severe and potentially longer in duration (Murray Darling Basin Authority, 2025)

For the cotton industry, this creates a two-directional squeeze. Agricultural water availability is being reduced from above through policy-driven environmental water recovery, and from below through declining inflows driven by a hotter, drier climate. The MDBP review is therefore not simply a debate about rebalancing environmental and agricultural allocations within a fixed resource, it is about managing a shrinking resource under intensifying competition. For growers, this convergence of policy and climate pressure translates into a production environment of compounding uncertainty. Investment decisions become harder to justify; crop area planning becomes more conservative and the boom-and-bust cycle that already characterises irrigated cotton production becomes more pronounced and more difficult to manage. The efficiency gains driven by higher water prices and tighter allocations are real, but they are increasingly being outpaced by the scale of the resource challenge itself.

I met with Zara Lowien, Chief Executive Officer of the National Irrigators Council (NIC), to discuss the broader political environment for water use in Australia. Australia is approaching a tipping point in efficiency, one that will begin to drive inefficiency and greater trade-offs, with implications that extend well past economic and environmental outcomes into the social and productive foundations that shape rural communities: namely the capacity of growers to adapt, the resilience of local economies, and the flexibility that has historically allowed farming systems to absorb shocks.

Figure 18: Meeting with MDBA Chief Executive Andrew McConville in Moree to discuss the challenges and opportunities in the MDBP review process (Source: Author).

UNITED STATES OF AMERICA

Across the US, the relationship between water governance and agricultural productivity plays out very differently depending on what state you are producing in. The contrast between Texas and Mississippi illustrates what governance means in practice. In Texas, groundwater from the Ogallala Aquifer has historically operated under the rule of capture. Effectively, the first one pumping gets it. Without enforceable limits on extraction, the aquifer has been drawn down at a rate far exceeding natural recharge, threatening the long-term viability of irrigated agriculture across the southern high plains. The response at the farm level has been adaptation out of necessity through deficit irrigation, more efficient systems and management practices designed to manage lower water input. But the reality is that the productive life of the water resource will end and irrigated agriculture will no longer be a mainstay in production systems.

Attending the Texas A&M AgriLife Water Symposium in Dallas in August 2025 as a guest of the Texas Water Resources Institute brought this into sharp focus. The challenges being faced far exceed agriculture. Municipal water supply has become the dominant topic of conversation, driven by exceptional population growth in major Texas cities. The pressure on a single resource from competing demands, including agricultural, urban and environmental is a preview of what inadequate water governance ultimately produces.

In Mississippi, the alluvial aquifer underpinning the Delta's highly productive agricultural system is showing early signs of the same trajectory. The National Center for Alluvial Aquifer Research (NCAAR), established by Congress in 2017 as a cooperative program between USDA and MSU, was created specifically to address water resource challenges in the Mississippi River Alluvial Aquifer where overdrawing the shallow productive aquifer was negatively impacting agricultural productivity, profitability and environmental outcomes. Visiting NCAAR during my study tour was a deliberate effort to understand the contrast in water availability and its effect on usage patterns.

One key difference compared to the Australian water framework was that the incentive to improve efficiency was driven by productive gains rather than economic ones. Growers often cited that water is cheap when you only pay the cost of pumping and essentially operate without regulation- a stark contrast to Australia, where water governance is sufficiently robust to drive water use efficiency alongside productivity gains.

It was sobering to learn from the Texas experience, but I left Mississippi optimistic that the research being done to understand the challenge will in time influence resource use efficiency outcome.

Figure 19: Attending the Texas A&M AgriLife Water Symposium, Dallas TX 2025. Pictured with Drew Gholson and Chris Delhom at NCAAR, Stoneville MS 2025 (Source: Author).

BRAZIL

Brazil presents a markedly different governance context, shaped not by scarcity but by the pace of expansion. Water is abundant but unevenly distributed. This has historically supported rapid agricultural expansion while masking emerging governance vulnerabilities (OECD, 2015). As one of the world's largest and most rapidly expanding cotton producers, Brazil's growth has been underpinned by government policies strongly orientated toward production, with significant investment in agricultural development, technology adoption and competitive export infrastructure driving record planted area and production forecasts.

Water resources are managed under the National Water Resources Policy (PNRH), established by Law 9,433/1997, which also created the National Water Resource Management System (SINGREH). The National Water Resources Council formally directs the policy, while the National Water and Sanitation Agency (ANA), established separately in 2000 is responsible for its implementation (OECD, 2024). The framework rests on a permit system — *outorgas* — that caps the volume a user may withdraw from a given water body, granted by whichever authority holds jurisdiction over that river, state or federal. In principle, this mirrors the entitlement logic underpinning the Murray-Darling Basin. In practice, the two systems diverge sharply on the lever that drives efficiency: price.

Where the MDB's entitlement trading system generates a genuine market price for water, water charging in Brazil — *cobrança* — remains the exception rather than the rule, implemented in only a handful of river basins nationally (OECD, 2017). Irrigated agriculture in the country's fastest-growing production frontier operates largely outside it. Growers pay for the infrastructure to extract and apply water, but in most cases not for the water itself. The result is an allocation system built on volumetric permits rather than price signals. And one that can cap use on paper without creating the same at-the-margin incentive to use water efficiently that price does.

This matters most in MATOPIBA in the Cerrado agricultural region spanning Maranhão, Tocantins, Piauí and Bahia, now one of the world's fastest-expanding cotton, soybean and maize production regions. Western Bahia has become a production powerhouse for irrigated cotton in Brazil, with centre-pivot irrigated area expanding rapidly on the Urucuia aquifer and the Grande River basin. A 2024 study by Brazil's National Space Research Institute (INPE), with Stockholm University's Stockholm Resilience Centre, found this expansion is now running ahead of the resource base: irrigation demand is projected to grow substantially by 2040, and the study warns that 30–40 per cent of that demand may go unmet across 2025–2040 as aquifer recharge and river flows decline under combined land-use and climate pressure (Martins, et al., 2024).

The parallel to the Murray-Darling Basin is instructive, but the sequencing is reversed. Australia built the governance and price architecture first, and efficiency gains followed under constraint. In Brazil, production and irrigated area have expanded first, and the governance and pricing architecture that would drive water use efficiency has not caught up. Whether that gap closes through policy, or through the resource constraint arriving, will determine whether Brazil's cotton growth continues on its current trajectory or is forced into the same efficiency reckoning already reshaping production in the Murray-Darling Basin and the US southern high plains.

Figure 20: Meeting at MAPA, the Ministry of Agriculture, Livestock and Food Supply and with the National Farmers union in Brasilia, Brazil 2025 (Source: Author).

Sustainability frameworks, ESG and the future of market access

The relationship between water use efficiency and market access is evolving. Increasingly, the sustainability of agricultural production systems, including how water is sourced, measured and managed, is becoming a consideration not only for regulators and governments, but for the brands, retailers and supply chains. For the cotton industry, this shift is creating both an opportunity and an obligation.

Sustainability certification frameworks have proliferated across the cotton supply chain. The Better Cotton Initiative (BCI), regenerative agriculture certifications and a growing number of supply chain traceability programs are increasingly being used by brands and retailers to verify the origin and sustainability credentials of the fibre they source. In Brazil, regenerative agriculture certifications are gaining traction as a market differentiation tool with increasing commercial value. For Australian cotton, which already operates under some of the world's most stringent environmental and water governance frameworks, these programs represent an opportunity to formalise and communicate a sustainability story that is largely already being lived.

Corporate ESG reporting obligations are increasingly requiring businesses to disclose and verify the environmental performance of their supply chains. This includes the sustainability of the agricultural commodities they source, creating a direct line between farm-level management and the reporting requirements of the brands and retailers that purchase Australian fibre. Access to green finance and sustainability-linked loans represent an emerging additional incentive, with financial institutions increasingly offering preferential lending terms to agricultural businesses that can demonstrate strong environmental credentials. As buyer demand for sustainable resource use data grows, the ability to measure, report and verify on-farm management will become an increasingly important component of both market and capital access over time.

The European Union's Green Deal represents the most significant policy signal of where this trajectory is heading. Visiting the EU Parliament and European Commission in Brussels during my Global Focus Program made the scale and ambition of the EU's commitment to embedding environmental standards across supply chains very evident. While the Green Deal's direct regulatory reach does not extend to Australian agriculture, its influence on the brands, retailers and manufacturers that purchase agricultural commodities, including cotton is increasingly material. Environmental reporting obligations, due diligence requirements and evolving standards around sustainable sourcing are reshaping how global supply chains are structured and what they demand from their suppliers.

For Australian cotton, this creates both a competitive imperative and a genuine opportunity. Brazil's rapidly expanding cotton sector is aggressively pursuing export market share, and its scale and cost competitiveness present a real challenge. The differentiating factor for Australian cotton is the quality, transparency and verifiability of its sustainability credentials. In a market where buyers are increasingly required to demonstrate the environmental integrity of their supply chains, Australian cotton's track record on water governance, environmental stewardship and traceability is a competitive asset but only if it is effectively measured, communicated and continuously improved. The risk of complacency is real. Maintaining the position as the producer of choice in premium markets will require not only sustaining current standards but actively demonstrating leadership as global expectations continue to rise.

There is a traceability project currently being undertaken by CRDC to directly address this opportunity. The Australian Cotton Industry Data Platform, led by CRDC, is an industry-owned digital infrastructure project designed to centralise data management, automate sustainability reporting and provide growers and supply chain partners with transparent, verifiable data. By making sustainability credentials more accessible, accurate and auditable across the supply chain, the platform positions Australian cotton to meet rising buyer expectations and defend its premium market position with confidence.

Figure 21: Pictured during GFP with country host Tessa Dimond at the European Parliament and outside the European Commission in Brussels, Belgium 2025 (Source: Author)

Global lessons

The clearest lesson from examining water governance across Australia, the US and Brazil is that policy settings matter. Not in an abstract sense, but in ways that directly shape what growers can plan, invest in and build over time. Where water is secure, tradeable and appropriately priced, growers invest with confidence in the infrastructure, technology and management systems that improve efficiency. Where governance is absent or uncertain, that confidence evaporates and the resource itself is often the casualty.

The Australian experience demonstrates that well-governed water markets can drive genuine efficiency gains. Texas illustrates with equal clarity what happens in the absence of governance, where aquifer drawn down with no mechanism to slow the decline is causing reallocation of water to its highest value use. Mississippi is watching that lesson unfold in real time and investing in research to get ahead of it. Brazil is expanding rapidly on the assumption of abundant water, an assumption that its own projections suggest deserves scrutiny. The clear observation across all three is that governance frameworks are far easier to build before a crisis than during one.

For the Australian cotton industry, the take-home is this: strong farm management and an enabling policy environment need to work in the same direction. When they do, systems improve, investment flows and water is used more efficiently. Navigating the convergence of policy reform and climate pressure will be one of the defining challenges for the Australian cotton industry in the decades to come and will ultimately require growers, industry and government to all be pulling in the same direction.

Appendix 2.5: Extended People and decision-making Research

People, knowledge and performance

Technology, policy and agronomic knowledge are enablers, but they only deliver their full value when the right people, with the right mindset, are making and implementing decisions. In semi-irrigated cotton systems, the limiting factor in water use efficiency is rarely technical, it is human. Every season presents a different set of constraints and opportunities, and the attitude and decision-making capability of the grower is the most powerful determinant of system performance. The growers who consistently outperform do so not because they have access to better tools or more water, but because they approach uncertainty differently; with clarity about their risk tolerance, discipline in their decision-making and the confidence to act when conditions allow. It is this capacity to capture upside, manage downside and build resilience over time that separates high-performing systems from the rest.

Relationships, networks and performance

High-performing production systems are rarely the product of a single decision-maker working in isolation. They reflect the quality of relationships between growers, agronomists and advisors who collectively translate research, monitor performance and adapt management in response to changing conditions. Agronomists and consultants are the bridge between research and the paddock. The best ones do more than interpret data and schedule inputs, they challenge assumptions, identify blind spots and provide the kind of external perspective that is difficult to generate from within a system. The most effective advisor relationships are characterised by trust, continuity and a genuine understanding of the farming business. Benchmarking extends this relationship beyond in-season support, converting data into meaningful insight, contextualising results against peers and historical trends, driving continuous improvement.

Grower networks and peer learning are equally important. Australian research consistently demonstrates that when producers collaborate, share knowledge and learn from each other's experience, research adoption is more likely to translate from reports into practice (Nettle, Major, Turner, & Harris, 2024). Group learning, peer-to-peer exchange and one-on-one advisory coaching are among the most effective extension methods for supporting farm practice change. The cotton industry's extension model includes field days, demonstration sites, regional grower groups and industry events providing a platform for knowledge exchange that formal research channels cannot replicate. Growers who actively participate in these networks consistently report earlier adoption of improved practices and greater confidence in management decisions.

Barriers to change

Barriers to change are rarely about access to information and they are more often about the conditions people act on it. Adoption decisions consume two limited on-farm resources- time and the capacity to integrate new information. Reducing the cost of accessing high quality, relevant information is one of the most effective ways to accelerate practice change.

Established systems, sunk costs in existing infrastructure, uncertainty about outcomes and the perceived risk of change relative to the status quo all constrain adoption. The transition to new systems, be it reduced till, modified irrigation infrastructure or cover cropping carries real costs in capital, time and production risk. Things often get worse before they get better when changing fundamental system components, and in farming systems where seasons are variable and margins are tight, that transition risk is a legitimate deterrent. The conservative instinct to stay with what has worked before is understandable, but it can also be the difference between a system that improves over time and one that stagnates.

Loss aversion compounds this further. Growers who have experienced a significant loss from trying something new are often the most resistant to future change. This is not because they lack the knowledge or ambition, but because the psychological weight of a past loss shapes how they evaluate future risk. This pattern is well documented in agricultural decision making and presents one of the most significant challenges for extension and advisory work. Rebuilding confidence after a negative experience requires not just better information, but demonstration, peer validation and the kind of trusted advisor relationship that allows a grower to take a considered risk within a supportive framework.

These barriers are not confined to the farm gate. The fragmentation of extension services and the increasing commercialisation of advisory roles have reduced the accessibility of independent, trusted guidance for many growers (Nettle, Major, Turner, & Harris, 2024). Where advice is commercially driven, the incentive to challenge established practices or advocate for system-level change can be subordinate to the immediate transaction. Addressing this gap through investment in independent extension, grower groups and industry-led demonstration programs is as important as generating the research that underpins practice change.

Australia's strong private consulting sector is a genuine competitive advantage and asset to the industry. The contrast with the US and Brazil was notable. In both countries, extension was delivered predominantly through a combination of government-supported university programs such as Texas A&M AgriLife and Mississippi State University in the US, and EMBRAPA in Brazil alongside agrochemical and seed company representatives. While these models deliver significant reach, the commercial incentives embedded in supplier-led extension can limit the independence and breadth of advice available to growers. Australia's private consulting model, at its best, offers trusted, system driven advice that is accountable to the grower rather than the product.

Risk perception and decision making under constraint

In semi-irrigated cotton systems, decisions are routinely made with incomplete information. Soil moisture, seasonal forecasts, water availability and market conditions are all known to an extent at the point when decisions must be made. How growers perceive and respond to that uncertainty is one of the most significant determinants of system performance. Australian research has found a surprising disconnect between farmers' climate risk perception and their adoption of climate-smart practices, with regional conditions, policy settings and socioeconomic context influencing adoption decisions more strongly than risk perceptions alone (Jalal et al., 2025). Simply raising awareness of risk is insufficient if the enabling conditions for action are not also in place.

Knowing your numbers is what creates those conditions. Growers who understand their true cost of production, know their break-even point and can evaluate the likely return on a management decision before committing to it are consistently better positioned to act with confidence under uncertainty. A clear understanding of the business removes the paralysis that uncertainty can create and replaces intuitive, emotionally driven decisions with ones grounded in evidence. This connects directly to the broader argument that agriculture is a business first, and that the discipline of understanding production economics is as important as any agronomic skill.

A practical illustration of this principle is the area-allocation decision under limited water. Growers can choose to *minimise area*, planting only what current allocation can fully water; *round up area*, taking on the risk of supplementary pumping or purchased water to finish the season; apply a *moderate deficit*, spreading water across a larger area and accepting an earlier cutout; or a *hybrid split*, watering a priority-one area to a known return while running a priority-two area on reduced water to capture upside from rainfall or supplementary pumping. Minimising area is the lowest-risk option, moderate deficit the highest. In a semi-irrigated context, though, the hybrid split offers the most compelling balance, the certainty of a fully watered crop on priority country, with the flexibility to capture upside when conditions allow. Making this call well depends on knowing the numbers behind each scenario, so decisions in-crop align with the grower's risk appetite. Chapter 3 develops this as a decision matrix.

Getting it right consistently is what separates reactive from proactive management and is the defining characteristic of the high-performing operators observed across this study tour.

Proactive vs reactive management

The distinction between proactive and reactive management is one of the clearest differentiators of high performing farms, and it is fundamentally a people characteristic, not a technical one. The tools, data and frameworks to support proactive decision-making are increasingly accessible. The limiting factor is the mindset and discipline to use them ahead of the decision-making window rather than in response to it.

Proactive management begins well before the season begins. Soil moisture monitoring, water accounting, configuration decisions, input planning and advisor engagement are all completed ahead of the sowing window, because the cost of being unprepared when opportunity arrives is too high. This is the operational readiness argument established in the chapter 1.2. The grower who is consistently positioned to act decisively when conditions allow gains a genuine and compounding competitive advantage over those constrained by logistical delays or late decision-making.

Technology amplifies this advantage, especially in the hands of growers and advisors who are already oriented toward proactive management. Monitoring platforms, canopy temperature sensors and decision support tools generate data that is most valuable when it is used to anticipate conditions and adjust management ahead of stress rather than confirm what is already visible. As discussed in chapter 1.3, the gap in semi-irrigated cotton is not data availability, it is interpretation and the willingness to act on what the data is saying before the season forces a response. Proactive growers use technology to extend their decision-making horizon. Reactive growers use the same tools to explain outcomes after the fact.

In-season, proactive management is expressed through the continuous reassessment of crop water demand against available supply. Adjusting irrigation scheduling, advancing cutout or scaling back input intensity when the numbers no longer support the original plan. The four-option water allocation framework outlined above is a practical expression of this. The grower who has evaluated each scenario before the season begins is not making a new decision when conditions change mid-season. They are executing a plan they have already prepared for. That preparation is what separates confident, adaptive management from reactive crisis response.

Post-season, proactive management becomes retrospective, using yield maps, water records, cost of production data and benchmarking results to evaluate what worked, what didn't and what to do differently. Growers who make proactive decisions, even under uncertainty, subsequently develop stronger risk perceptions and greater adaptive capacity over time, creating a feedback loop between action and awareness that compounds across seasons (Wheeler, Nauges, & Zuo, 2021). The habit of critically evaluating performance and adjusting the system in response is what drives continuous improvement. This was a defining characteristic of the high-performing operators observed across my study tour.

Appendix 3: Cotton Industry Gross Margins 2025-26

AgEcon

Cotton Industry Gross Margins

2025-26

CottonInfo

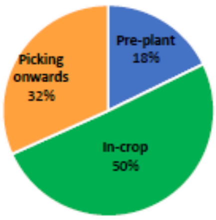
Gross Margin Budget: Furrow Irrigated Cotton

1m row spacing. Bollgard3®, XtendFlex®, Roundup Ready Flex®

INCOME:				Example Budget $/ha	Your Budget $/ha
12.0	bales/ha[1] @	Cotton lint	$573 /bale (at gin)	$6,876	
		(less quality discount)	-$8 /bale (at gin)	-$96	
		Cotton seed	$93 /bale (at gin)	$1,115	
			$658 /bale (at gin)		
			A. TOTAL GROSS INCOME $/ha:	$7,895	

VARIABLE COSTS:

See pg 2 for details



	Example Budget $/ha	Your Budget $/ha
Fallow management	$70	
Farming: Pre-planting	$65	
Nutrition	$989	
Planting	$145	
Irrigation (6.5 ML applied[2])	$551	
Insurance	$272	
Crop protection, application & licence fee	$906	
Defoliation	$131	
Picking, cartage & ginning	$1,332	
Farming: Post-crop	$120	
B. TOTAL VARIABLE COSTS $/ha:	$4,580	
GROSS MARGIN* (A-B) $/ha:	$3,315	
GROSS MARGIN (A-B/ML sourced[3]) $/ML:	$422	

Break even yield (bales/ha) based on lint & seed prices above:	5.5 bales/ha
Break even price ($/bale incl. seed and discounts) based on 12 bales/ha:	$361 /bale

Note that break even yield & price are for variable costs only, overhead costs and labour are NOT considered

SENSITIVITY TABLE[5]

227kg lint bales/ha	PRICE ($/bale incl. of seed & discounts) 558	608	658	708	758
9.0	850	1284	1719	2153	2588
10.0	1285	1768	2251	2734	3216
11.0	1721	2252	2783	3314	3845
12.0	2156	2736	3315	3894	4474
13.0	2592	3219	3847	4475	5102
14.0	3027	3703	4379	5055	5731
15.0	3463	4187	4911	5635	6360

COTTON PRICE HISTORY & TRENDS

This budget is designed to give an indication of operations and costs required to grow a cotton crop. Prices are estimates only. A grower should alter this budget to take account of individual field management plans, movements in crop and input prices and changes in seasonal conditions. In all instances, operations should be tailored to the requirements of individual paddocks. For a complete guide to cotton management, see the ***Australian Cotton Production Manual.***

PAGE 1

Cotton Industry Gross Margins
2025-26

Gross Margin Budget: Semi-irrigated Cotton, double skip

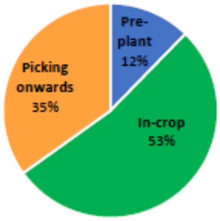
1m row spacing. Bollgard3®, XtendFlex®, Roundup Ready Flex®

INCOME:

				Example Budget $/ha	Your Budget $/ha
7.0	bales/ha[1] @	Cotton lint	$573 /bale (at gin)	$4,011	
		(less quality discount)	-$8 /bale (at gin)	-$56	
		Cotton seed	$93 /bale (at gin)	$651	
			$658 /bale (at gin)		
			A. TOTAL GROSS INCOME $/ha:	$4,606	

VARIABLE COSTS:

See pg 2 for details



	Example Budget $/ha	Your Budget $/ha
Fallow management	$70	
Farming: Pre-planting	$65	
Nutrition	$377	
Planting	$47	
Irrigation (3.6 ML applied[2])	$210	
Insurance	$183	
Crop protection, application & licence fee	$649	
Defoliation	$88	
Picking, cartage & ginning	$784	
Farming: Post-crop	$120	
B. TOTAL VARIABLE COSTS $/ha:	$2,594	
GROSS MARGIN* (A-B) $/ha:	$2,011	
GROSS MARGIN (A-B/ML sourced[2]) $/ML:	$471	

Break even yield (bales/ha) based on lint & seed prices above:	3.1 bales/ha
Break even price ($/bale incl. seed and discounts) based on 7 bales/ha:	$348 /bale

Note that break even yield & price are for variable costs only, overhead costs and labour are NOT considered

SENSITIVITY TABLE[5]

227kg lint bales/ha	PRICE ($/bale incl. of seed & discounts) 558	608	658	708	758
4.0	42	234	426	618	810
5.0	474	714	954	1194	1434
6.0	907	1195	1483	1771	2059
7.0	1339	1675	2011	2347	2683
8.0	1772	2156	2540	2924	3308
9.0	2204	2636	3068	3500	3933
10.0	2637	3117	3597	4077	4557

The Southern Oscillation Index (SOI)

The Southern Oscillation Index (SOI) represents the atmospheric component of ENSO. This has a strong impact on water budgets and early season crop evapotranspiration.

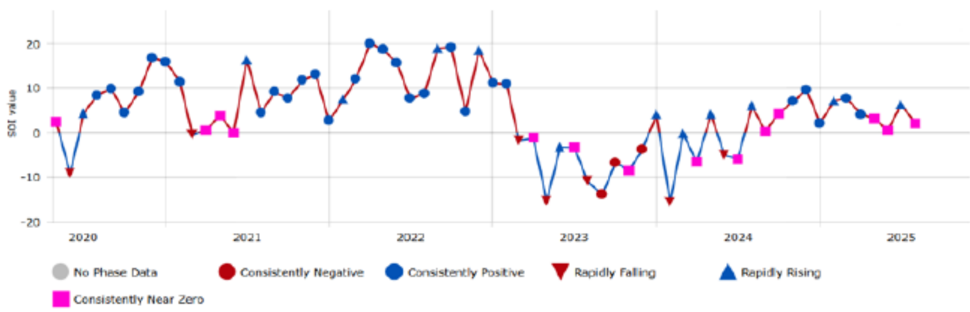


Chart source: The Long Paddock (QLD Gov) 2025

This budget is designed to give an indication of operations and costs required to grow a cotton crop. Prices are estimates only. A grower should alter this budget to take account of individual field management plans, movements in crop and input prices and changes in seasonal conditions. In all instances, operations should be tailored to the requirements of individual paddocks. For a complete guide to cotton management, see the ***Australian Cotton Production Manual.***

2025-26 Cotton Gross Margins, brought to you by the cotton industry's joint extension program, CottonInfo.

Foot notes

***GM/Ha**: This gross margin represents the income and costs for 1 green hectare of cotton plus the required refuge crop of 0.025ha, resulting in a total gross margin area of 1.025 ha.

1. Yield: Actual yields are a complex result of agronomic and environmental factors. In this budget a yield of 12 bales/ha is appropriate considering the long fallow, fertiliser program and budgeted irrigation water.

2. Water: Budgeted water is the ML/ha pumped from sources (surface or groundwater). Grower Survey data shows a 5 year average (2019-20 to 2023-24) *field applied water* of 6.4 ML/ha. Water application for refuge pigeon peas is estimated at 3.7 ML/ha, giving total cotton (1 ha) and refuge (0.025 ha) water use of 6.5 ML/ha. Average conveyance efficiency of 83% (NSW DPI 2020-21 and 2021-22) brings *total sourced water* to 7.8 ML/ha (cost outlined on pg2). Individual water budgets will vary depending on irrigation system efficiency, and regional and seasonal variations in plant evapotranspiration and effective rainfall.

3. Cost of water: The cost of applied irrigation water varies considerably depending on: source (groundwater, surface water), number of times pumped to get to field, energy source of pumps, and relevant fees and charges. This budget assumes 79% surface water and 21% groundwater (2021-22 to 2022-23 Grower Surveys), with a total surfacewater cost of $64/ML (extract and lift to storage) and a groundwater cost of $83/ML (extract only), both including pump fuel and maintenance and water usage charges.

4. Chemicals: Registrations vary between states. Use of a particular brand name or active ingredient are examples only and do NOT imply a recommendation. Always read chemical labels and follow directions. XtendFlex® varieties allow 'Over the Top' application of glyphosate, dicamba and glufosinate-ammonium herbicides under specific conditions. With a range of traits being grown this season, ensure all weed management strategies are trait specific.

5. Sensitivity tables: There are yield dependant costs included in these calculations.

Machinery costs: The cost of each farming pass reflects variable costs only (fuel, repairs and maintenance), labour and depreciation are considered overhead costs, so are not included in this budget. Contractor rates encompass these costs and are outlined in a separate budget.

See the **Gross Margin Notes** for further details on assumptions.

Acknowledgements
We wish to acknowledge the efforts made by industry specialists and management during the development and review of the 2025 cotton gross margin budgets. Assistance was provided by retailers, agronomists, the CottonInfo team, CCA, and CSD.

Appendix 4: Semi-irrigated hybrid model case study

Case Study Overview

Date: 25/03/26

Location / Farm: Chesney, Mallawa

Grower: Mick Humphries

Soil type / variability: Black cracking vertosols

Farming system (rotation): Cotton → Barley → Semi-irrigated cotton

Starting position

Water & Soil

Starting soil moisture profile: 120mm, should get to 160-180mm pre plant

Water allocation / availability: Can align to strategy, 2 tier strategy

Irrigation capacity: Priority 1 area- fully irrigated 1m (100%) Priority 2 area- skip row semi-irrigated

Seasonal Context

Seasonal outlook: Less general rainfall more storms

Key risks: Capped yield potential without in crop rain. Less return and reduced consistency achieved with low in crop rainfall.

Expected in crop rainfall- 10 yr mean 280mm

Decision Point

Why consider semi-irrigated cotton? Historical Yield is poor due to disease, no longer feasible to grow fully irrigated and maintain profitability targets. Has been pulled out of fully irrigated cotton production until redevelopment

Alternative options: Given it is on the flat with standing stubble, it could stay in winter crop rotation. Ie. Canola or Faba beans

Why cotton over alternatives? Returns, best water use in $/ML

Opportunity vs risk decision? It provides a learning opportunity as we look at long term water availability and options for Chesney moving forward

What would stop planting? Fertiliser availably and needing to prioritise priority 1 area

Defining the system

Crop Strategy

Planting window: November but will go earlier with planting moisture and manage architecture accordingly.

Variety: talked about defensive vs opportunistic strategies 619 & 606 eq- maybe 320/1257 on higher water allocated crop?

Plant population: 8-10p/m, prioritising uniformity. If we get to mid-November going to 10-12pl/m

Row configuration: Discussed 2m vs 60in vs DS/SS

Low water input- Double skip

Mod water input- single skip

High water input- 1m

Irrigation Strategy

Number of irrigations:

Field 1	3 waters, 4-5ML/ha total → 5-6b/ha yield target
Field 2	5 waters, 6-7ML/ha total → 8-10b/ha yield target

Timing: Push crops hard early to maximise root system

Flexibility: For field 1, very little, strategy is driven by efficiency and harvest index. For field 2, may water earlier to support crop architecture and future yield potential.

Nutrition Strategy

Strip Till and put down NPK blend, aim for 30:30:30

From soil tests there is 40units N available/ha on average.

Strategy for urea- upfront + 1 in crop spread

Water Use Efficiency Lens

Water Capture

Fallow management: To date, very sound. Residuals have worked well, camera work predominately.

Constraints: wheel tracks, 2m and 3m wheel tracks mean surface compaction limits infiltration and WHC in some areas.

Water Storage

Stored moisture: Even without decent winter rainfall very decent profile to plant on.

Soil limitations: surface moisture at planting and dry down from Strip tilling.

Water Use

Priority: Return per ML, disease risk minimisation

Decision tools: Will utilise probes, canopy temperature sensors

Risk and Decision Framework

Risk attitude: Optimistic

Biggest risks: boom bust cycle moving from defensive to aggressive approach, exposure to markets

Decision indicators: land rich water poor or water rich, land poor

Trigger points: System rather and $/ML due to disease

Plant physiology and Agronomy

Establishment and Early vigour: Prioritise a good start, early vigour, uniformity and good root development

Retention: strategy is aggressive, not giving away moisture or lengthening season

Growth regulation: Pix management approach will be systematic rather than reactive, prioritising an efficient plant type. Small doses earlier.

Irrigation: Push first water as hard as you can to set up root exploration in the skip

System Constraints

Ideally you would fully irrigate cotton 1 in 2yrs, but it is not feasible here due to water and disease constraints. Looking at long term shift in system at Chesney to maximise profitability.

Pie in the sky is 30/60inch, limited tillage, CTF, retained stubble in a irrigated system rather than crop (supplementary irrigation).

For now, target is having Priority 1 area (50%) in hills ready for fully irrigated cotton production, Priority 2 area (50%) on the flat in standing stubble to provide flexibility in planting options and maximise planting opportunities in the absence or reduction in irrigated water availability

Machinery: 8m planter limits configuration options and the cost/commitment to a complete system change is hindered by transition time and contractor challenges

External pressures: water policy changes, likely to see a more elongated boom bust. Moving forward we are likely to see an ease in to wet (watch water go past).

Economics and Performance

Success metrics: $ return/ML, matching input to output

Biggest priority is matching input to output, manage costs and remain adaptive in season to scale up or back with seasonal conditions and yield potential.

Break-even point: Gross margins to be performed on target yield of 5b/ha and 8b/ha

Reflection on previous experience

Previous experience: 748, 7pl/m on a solid plant.

What worked: planted into moisture, pix management- small doses earlier, harder was better

What would change: Challenges in establishment on head ditch, if conditions are good- go