FINAL REPORT

Cropping systems in the Daly River catchment, present and future

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Acronyms

AAM/ AAMIG	AAM Investment Group
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
CRC	Cooperative Research Centre
CRDC	Cotton Research and Development Corporation
CRCNA	CRC for Developing Northern Australia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DDRF	Douglas Daly Research Farm
DRC	Daly River Catchment
EAV	Equivalent Annual Value
ENSO	El Niño-Southern Oscillation
FAO	Food and Agricultural Organisation
GM	Gross Margin
GPWUI	Gross Production Water Use Index
IOD	Indian Ocean Dipole
KAI	Kimberley Agricultural Investment
MJO	Madden-Julian Oscillation
ML	Megalitre
NAIF	Northern Australia Infrastructure Facility
NT	Northern Territory
NTG	Northern Territory Government
NWI	National Water Initiative
NPV	Net Present Value
NSW	New South Wales
OECD	Organisation for Economic Cooperation and Development
OIAMC	Ord Irrigation Asset Mutual Co-operative
OIC	Ord Irrigation Co-operative
ORIA	Ord River Irrigation Area
RIWI	Rights in Water and Irrigation Act 1914
QLD	Queensland
WA	Western Australia
WUE	Water Use Efficiency

Project Participants



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Executive Summary

For the past decade, Australian and Northern Territory (NT) government policy has actively encouraged the development of irrigated agriculture in northern Australia, with access to water identified as a central motivator. In the Daly River catchment, one of the few catchments in the NT with reliable year-round water, development must occur within a hydrologically sensitive, groundwater-dependent system that also holds high ecological and cultural value, and it depends on access to both water for irrigation, and to provide confidence and ongoing investment to further develop the region. The primary aim of this report is to provide the social and economic evidence needed to understand what enables, and what constrains, sustainable agricultural development in the Daly River region. The work has been undertaken to deliver Project 2.4 of the CRC for Developing Northern Australia (CRCNA) Water Security Program. The work is extended in Project 4.1, which examined prospects for new agricultural technology with a focus on the Fitzroy region in Queensland (but included some work in the Daly region).

Decisions about agricultural development depend not only on whether allocatable water is available, but on whether crops can be grown profitably and investments can be made with confidence. These questions are economic and social as much as hydrological. The security and time frame of water entitlements, how the costs and returns of different crops compare, and how efficiently each crop uses water all shape whether development can proceed and whether these developments will prove to be sustainable. This report addresses these questions, combining the perspectives of the people developing the region with desktop analyses of the crops most likely to be grown. Because these analyses were undertaken as separate investigations, their assumptions and methods differ, and their findings are method-dependent rather than directly comparable.

The report provides three main outputs, supported by a baseline description of the soils and climate (Section 2):

- A mixed methods social science investigation, drawing on interviews with growers, suppliers and contractors, comparing irrigated development in the Douglas Daly region of the NT with the more established Ord Irrigation Area in Western Australia, to identify the conditions under which growers invest with confidence (Section 3).
- A detailed economic and water-use analysis of cotton, combining 20-year Net Present Value modelling, water-use efficiency estimates, and sensitivity testing against future water pricing, to assess the viability of irrigated and rainfed systems in the catchment (Section 4).
- A desktop review of the production costs, economic performance and water use of established NT crops, including mango, watermelon, Asian vegetables and hay, providing a baseline for considering water-use efficiency across the sector (Section 5).

Across these outputs, a consistent theme emerges: the certainty of access to water shapes whether growers invest. Interviews show that where governance frameworks do not provide certainty, individual growers default to caution, and the broader regional opportunity is deferred. In comparison, the more secure collective entitlements of the Ord Irrigation Cooperative in Western Australia (used as a comparison) have supported its progress toward commercial self-sufficiency. Economic analyses found that crops can be viable in the region, with cotton viable under irrigated

systems and several established horticultural and fodder crops returning positive margins, but that this viability is sensitive to the assumptions used, including the irrigation system, market factors, and the future cost of water. The report draws these findings together into a small set of strategic recommendations (Section 6). These address the relationship between secure water access and grower investment, and the scope to improve water-use efficiency, while emphasising that any move toward longer-term water access must rest on allocations that are demonstrably sustainable on the evidence.

1 Introduction

1.1 Background and purpose

This report has been prepared as part of the Water Security Program of the CRC for Developing Northern Australia. The work was conducted to investigate the role that access to water plays in agricultural outputs and planning in the Northern Territory, with a focus on the Daly River catchment. Specifically, the work uses a combination of mixed methods social science investigations and desktop-based economic analyses of the viability of multiple crops. The work presented here is extended by work conducted under Project 4.1 of the Water Security Program (Prospects for new agricultural technology across northern Australia), which focused on the Fitzroy region in Queensland, but also included work including growers in the Daly region.

The work included here is set within the context of a decade in which Australian and Northern Territory government policy has actively promoted the development of agriculture in northern Australia. The Commonwealth of Australia (2015) White Paper on Developing Northern Australia identified agriculture, underpinned by access to water for irrigation, as a key growth opportunity. That ambition has since been supported through mechanisms such as the Northern Australia Infrastructure Facility (NAIF), established in 2016 to provide concessional finance, and the Northern Australia Action Plan 2024 to 2029, which sets a target of a 100 billion dollar agriculture, fisheries and forestry industry by 2030 (Australian Government, 2024).

The Daly River catchment is a natural focus for this ambition. Covering over 520,000 km^2, it is a catchment in northern Australia that largely has access to reliable year-round water, sustained by groundwater discharge from extensive karst aquifers including the Tindall Limestone and Oolloo Dolostone (Department of Environment and Natural Resources, 2019; Department of Environment, Parks and Water Security, 2024). These aquifers maintain flows in the Daly River through the dry season, a characteristic shared by only a small number of northern rivers. The catchment also contains fertile alluvial soils along its floodplains that supports an established horticultural industry. For example, the Northern Territory produces around half of Australia's mangoes (Northern Territory Government, 2026), with the Daly region the centre of that production. The Daly also hosts an emerging cotton industry served by a new processing facility at Katherine, and a long history of agricultural research at the Douglas Daly Research Farm. Despite these advantages, cropping still occupies less than two per cent of the catchment, and agricultural development across the region remains limited.

The reasons for this slow progress are central to this report. Development in the Daly is not constrained by any single factor but by an interacting set of interrelated factors: the high capital cost of establishing groundwater-fed irrigation; the difficulty of identifying crops and systems that are reliably profitable under tropical wet-dry conditions; uncertainty over access to water; and the ecological and cultural sensitivity of groundwater and the ecosystems that it sustains in the region.

The report addresses these factors by capturing the perspectives of the growers, suppliers and contractors developing the region, and by assessing the economic viability and water use of the crops most likely to be grown there, drawing on a baseline description of the catchment's soils and climate. It is intended to support agricultural and water-planning agencies, and growers in making evidence-based decisions about agricultural development in the Daly. By combining the perspectives of the growers, suppliers and contractors developing the region with an assessment of the economic viability and water use of the crops most likely to be grown there, and by setting both against a baseline of the catchment's soils and climate, the report is intended to support the

Department of Industry, Tourism and Trade, water-planning agencies, and growers in making evidence-based decisions about where and how agricultural development can proceed.

1.2 Project objectives

The project set out to inform agricultural development and water management in the Daly River catchment. It pursued four objectives:

1. To compile a baseline of the soils, climate, vegetation and land use of the Daly River catchment, providing the environmental context within which agricultural development and water-use options are assessed (Section 2).
2. To use mixed methods social science, centred on interviews with growers, suppliers and contractors, to understand landholders' approaches to farming, the uptake of agricultural technology, and their perspectives on access to water and how it shapes farming and investment decisions (Section 3).
3. To assess the economic viability and water use of candidate cropping options for the catchment through desktop economic analyses, covering broadacre cotton and a range of established horticultural and fodder crops (Sections 4 and 5).
4. To draw these strands together to identify the economic implications of potential changes to farming practices and water management, and to set out strategic recommendations for sustainable agricultural development in the catchment (Section 6).

These objectives were pursued through two main streams of work: a mixed methods social science investigation of how landholders experience and make decisions about irrigated development, and a set of desktop economic analyses of the costs, returns and water use of candidate crops. Both are supported by the soil and climate baseline, and both inform the recommendations.

1.3 Scope of report

This report brings together a set of investigations carried out under Project 2.4. Each was developed largely independently, addressing a different aspect of agricultural development in the catchment, and they are compiled here under a common banner. Some repetition between sections is therefore unavoidable, particularly in describing the catchment, its water-governance setting, and its soils and climate. Each section also retains the methods and assumptions of the investigation it reports.

Following this overview (Section 1), Section 2 presents a baseline description of the Daly River catchment's climate, soils, vegetation and land use, drawing together existing datasets and literature to establish the environmental context for the analyses that follow.

Section 3 presents the mixed methods social science investigation. It compares the experiences of landholders in the Douglas Daly region of the Northern Territory and the Ord Irrigation Area in Western Australia, drawing on interviews with growers, suppliers and contractors. The section uses the stages of irrigation development, and the incentives that shape grower investment, to explain why development has progressed differently in the two regions and what each can learn from the other.

Sections 4 and 5 present the economic analyses. Section 4 is a detailed economic and water-use analysis of cotton, combining twenty-year net present value modelling, water-use efficiency estimates, and sensitivity testing against future water pricing. Section 5 is a desktop review of the production costs, economic performance and water use of established Northern Territory crops,

namely mango, watermelon, Asian vegetables and hay, intended as a baseline for considering water-use efficiency across the sector. An additional analysis of the results of long term field trials in the area is provided in Appendix 3.

Because these economic analyses were conducted as separate investigations, they differ in scope, data sources, time horizons and assumptions. Section 4 applies long-term net present value modelling to a single broadacre crop, whereas Section 5 reports indicative annual gross margins drawn from a desktop review across several established crops. Their headline figures should therefore be read as indicative and method-dependent. Apparent differences between the two analyses often reflect differences in how each was conducted, for example the financial metric used, the discount rate applied, or the assumed water-use and price data, rather than directly comparable differences in the performance of the crops themselves. Where comparison across the analyses is warranted, the report sets out the basis on which it is made.

Section 6 draws on the social and economic findings, and on the soil and climate baseline, to present a small set of strategic recommendations. These address, among other matters, the relationship between water access and investment, and the scope for improving water-use efficiency, that emerge from the preceding sections.

2 Overview of soil and climate in the Daly region, Northern Territory

2.1 Climatic and Environmental Characteristics of the Daly River Catchment

2.1.1 Rainfall

The Daly River catchment experiences a tropical monsoonal climate characterised by distinct wet and dry seasons (Duvert et al., 2022). Rainfall is strongly seasonal, with most precipitation occurring during the wet season between November and April (Figure 2.1b, Warfe et al., 2011). During this period, monsoonal systems and occasional tropical cyclones generate intense rainfall events that drive river discharge and floodplain inundation across the catchment (Alexander et al., 1999). In contrast, the dry season from May to October is typically characterised by very low rainfall and high evapotranspiration rates (Chan et al., 2012).

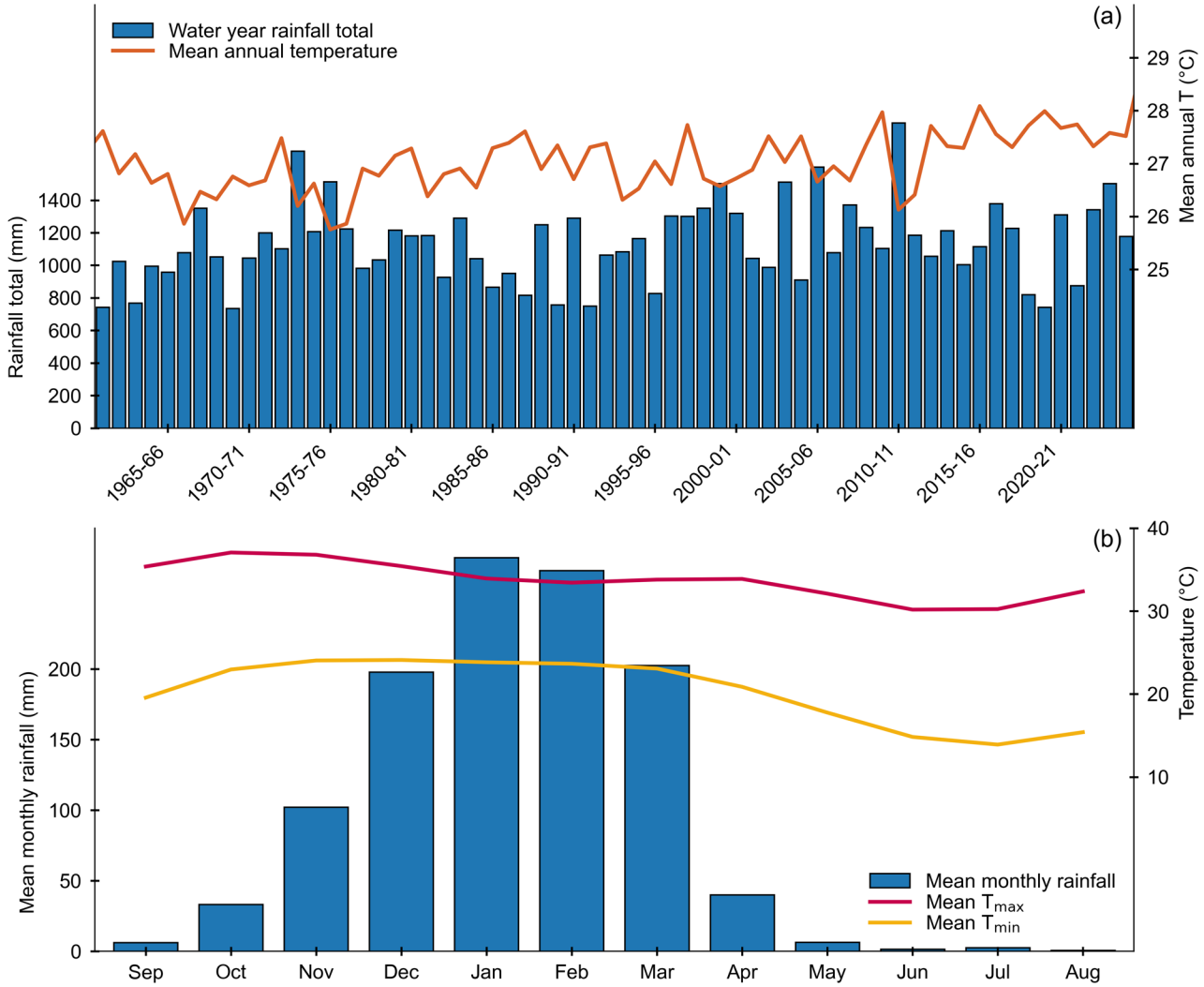


Figure 2.1 Catchment averaged rainfall and temperature data from the Daly River catchment. The average of 30-points throughout the catchment shown. Data from the SILO database (Queensland Government, 2026).

Average annual rainfall across the catchment varies spatially. Southern parts of the catchment generally receive around 600–800 mm annually, while northern and coastal regions may receive

more than 1,200–1,300 mm per year (Bureau of Meteorology, 2018, 2024b; Figure 2.1a). This rainfall gradient significantly influences hydrological processes and ecological patterns. Areas with higher rainfall and proximity to major waterways tend to support denser vegetation communities and wetter ecosystems compared with the drier upland landscapes (Petty and Douglas, 2010; Woinarski et al., 1999).

Rainfall variability also drives river hydrology and wetland connectivity. During the wet season, high rainfall results in widespread flooding and surface runoff, which recharge groundwater systems and inundate floodplains (Irvine et al., 2026). In the dry season, baseflow in the Daly River is sustained by groundwater discharge from extensive limestone aquifers underlying parts of the catchment (Pusey et al., 2020; Webster et al., 2005). This groundwater contribution maintains perennial flow conditions, distinguishing the Daly River from many other northern Australian rivers that cease flowing during the dry season (Knapton, 2006; Pusey et al., 2020).

Interannual climate variability further influences rainfall patterns. Large-scale climate drivers such as the El Niño–Southern Oscillation and the Indian Ocean Dipole affect rainfall intensity, seasonal onset, and total precipitation across northern Australia (Risbey et al., 2009). These climate oscillations can alter flood frequency, wetland inundation, and vegetation productivity within the Daly River catchment (Cartwright et al., 2025).

2.1.2 Soils

Soils in the Daly River catchment are highly variable and are closely related to underlying geology, landforms, and hydrological conditions (Wasson et al., 2010). The catchment contains a combination of upland soils derived from sandstone and lateritic formations, as well as fertile alluvial soils deposited by riverine processes along floodplains and river channels (Wasson et al., 2014; Wilson et al., 2006).

In upland areas, soils are typically sandy, shallow, and relatively low in nutrients. These soils commonly develop over sandstone plateaus and lateritic surfaces and are generally well-drained (Robson et al., 2010; Rustomji and Caitcheon, 2010; Stace et al., 1969). Such soil conditions favour open savanna vegetation dominated by Eucalyptus species and seasonal grasses (O'Grady et al., 2000; Wilson et al., 2006). However, the limited fertility and water-holding capacity of these soils restrict the development of dense forest vegetation (Begg and Lowry, 2003; O'Grady et al., 2000).

In contrast, soils along river corridors and floodplains are more fertile and often consist of alluvial sediments deposited during flood events (Lal et al., 2015) also characterised as Vertosols soil type (Northern Territory Government, 2025; Searle, 2021). These soils typically contain higher levels of organic matter and nutrients and may range from sandy loams along levees to silty and clay-rich soils in floodplain depressions (Rustomji and Caitcheon, 2010). Floodplain soils have greater moisture retention capacity and support productive wetland ecosystems (De Groot et al., 2007; Ndehedehe et al., 2020b).

The Daly River catchment also contains extensive karst landscapes associated with limestone geology (Faulks, 1998; Pantus et al., 2011). These formations host large groundwater aquifers that influence soil moisture and hydrological processes across the region (Gow et al., 2018; Lal et al., 2015). The interaction between soil properties, groundwater systems, and surface water dynamics plays a critical role in shaping vegetation distribution and ecological productivity (O'Grady et al., 2006). Thus, soil patterns within the catchment form a mosaic of upland sandy soils, fertile alluvial deposits, and seasonally waterlogged floodplain soils (Northern Territory Government, 2025). These soil characteristics strongly influence vegetation communities and land-use suitability across the catchment (Bahadori et al., 2022).

2.1.3 Vegetation

Vegetation across the Daly River catchment reflects interactions between rainfall patterns, soil properties, topography, and hydrological processes (Petty and Douglas, 2010). The landscape is dominated by tropical savanna ecosystems, which cover much of northern Australia and consist primarily of open Eucalyptus woodlands with a grass-dominated understory (Walton and Fitzsimons, 2015).

Vegetation patterns vary with topography and hydrology, comprising upland woodlands, levee forests, and extensive floodplain vegetation communities (Faulks, 1998; Land Planning Environment, 2026; Petty and Douglas, 2010). Upland regions are typically dominated by open savanna woodlands growing on well-drained soils. These ecosystems experience frequent fire regimes and strong seasonal variability in grass cover (Edwards et al., 2015; Russell-Smith et al., 2003).

Riparian zones along major rivers support denser vegetation communities due to the availability of moisture and nutrient-rich soils communities (Faulks, 1998; Petty and Douglas, 2010). These areas include closed monsoon forest fringes and riparian forests with species, such as *Nauclea orientalis*, *Terminalia microcarpa*, and *Casuarina cunninghamiana*, as well as riparian species including *Melaleuca leucadendra* and *Melaleuca argentea* (Fogarty and Gibbs, 1976; NVIS Technical Working Group, 2017).These vegetation communities are important ecological refuges during the dry season (O'Grady et al., 2006).

Floodplains support seasonally inundated vegetation dominated by grasses, sedges, and Melaleuca forests (de Mello et al., 2025). Seasonal flooding replenishes nutrients and maintains high productivity within these wetland systems (Perna et al., 2026). Floodplain wetlands provide essential habitat for fish, birds, and other wildlife (King et al., 2021; O'Mara et al., 2024).

In the lower reaches of the catchment, estuarine areas support mangrove communities (Northern Territory Government, 2024a; Wolanski et al., 2006). Although relatively limited in extent compared with coastal estuaries elsewhere in northern Australia, these mangroves include species, such as *Avicennia marina* and *Rhizophora stylosa* (Faulks, 1998). These coastal ecosystems play important roles in coastal protection, sediment trapping, and habitat provision. Vegetation patterns across the Daly River catchment form a complex mosaic shaped by hydrology, soil properties, and climatic variability (De Groot et al., 2007).

2.1.4 Land Use

Land use within the Daly River catchment includes a mixture of conservation areas, pastoralism, agriculture, and limited mining. Large areas of the catchment are protected within national parks and conservation reserves, including Litchfield and Kakadu National Parks activities (Northern Territory Government, 2024b). These protected areas preserve biodiversity and maintain ecological processes within the region (De Groot et al., 2007).

Pastoralism is one of the dominant land uses across the catchment. Grazing occurs primarily on cleared savanna woodland areas and typically operates at relatively low stocking densities of approximately four animals per square kilometre (Russell-Smith and Sangha, 2018). Extensive cattle grazing reflects the large property sizes and relatively low population density across northern Australia (Hunt et al., 2014).

Land use within the catchment includes a mix of conservation, pastoralism, and agriculture. Large areas are protected within Litchfield and Kakadu National Parks, while cleared areas are primarily used for grazing, typically at low stocking densities (Hermoso et al., 2018; Zander et al., 2013) (e.g.,~4 animals km^2). However, there is increasing pressure from irrigated agriculture, mining, and

settlement expansion, with further development anticipated following the end of clearing moratoriums in 2010 and 2020 (Townsend and Padovan, 2009).

The catchment also supports mineral extraction, including gold mining at Mt Todd (Daly River Management Advisory Committee, 2009). Although mining activities remain limited in spatial extent, they represent potential environmental pressures on water resources (Bartolo et al., 2012; van Dam et al., 2008).

Recent developments include the construction of a cotton processing facility in Katherine, reflecting growing interest in agricultural expansion across northern Australia (Ash et al., 2017; Ash and Watson, 2018). Government policies promoting northern development have further increased attention on the Daly River region as a potential agricultural hub (Adams and Pressey, 2014; Jackson, 2006).

Despite these developments, the Daly River catchment remains relatively undisturbed compared with many other Australian river systems. The region has a small population of approximately 12,000 people, limited urbanisation, and relatively low levels of point-source pollution (Townsend, 2025). However, agricultural land-use and clearing of savanna woodland have gradually increased since the late 1970s (Lawes et al., 2015). Sustainable land management strategies will therefore be important to maintain the ecological integrity of the catchment.

3 Challenges in Developing Agricultural Water Use in Northern Australia: A Comparison between Douglas Daly and the Ord Irrigation Scheme

Authors: Megan Star, John Rolfe, Ukamaka G. Nwobodo

3.1 Overview of approach

The interviews conducted for this work were undertaken alongside a parallel set of interviews in the Ord Irrigation Area, using the same approach and similar lines of questioning. This approach was shared with related work under Project 3.3 of the CRCNA Water Security Program and allows the responses from the two regions to provide contrast against other settings. The Ord is therefore included here as an additional case study, providing a more established scheme against which development in the Douglas Daly can be understood. Lessons drawn from the Ord's longer trajectory help frame the conditions that shape investment in the earlier-stage Daly. An additional summary of the Daly-related interviews is provided in Section 8.1.

3.2 Introduction

In 2015 the Australian Government reconfirmed its commitment to Northern Australia with the development of a White Paper (Australian Government, 2015). Among other strategies this identified agriculture as a key growth opportunity through potential access to water for irrigation. Over the past decade, opportunities for greater agricultural development have been supported through initiatives such as the creation of the Northern Australia Infrastructure Facility (NAIF) in 2016 to provide concessional finance for projects and the progress of stages 2 and 3 of the Ord River Irrigation Area. The Northern Australia Action Plan 2024-2029 was released by the Office for Northern Australia with the aim of supporting a $100 billion agriculture, fisheries, and forestry industry by 2030, with support for several focus areas to underpin the strategy (Office of Northern Australia, 2024).

Despite the attention on agricultural development and the provision of different support mechanisms, progress has been limited. There are several potential reasons for this, including factors such as the costs of agricultural development and operation, difficulties in identifying suitable crops, issues about water supply and security, and the challenges of managing development process that minimise environmental impacts in ecologically sensitive areas. One strategy emerging to address this has been to focus support on place-based infrastructure and opportunities so as to tailor development to the constraints of particular areas and situations (Infrastructure Australia, 2021).

The development of water resources and irrigated agriculture in southern Australia followed very different pathways to northern Australia. Much of the development in southern Australia occurred before concerns about environmental impacts became widespread, with major infrastructure and water distribution systems often planned, funded, and built by the government (Bennett, 2008; Kirby et al., 2014). In this context, the challenges for irrigation development were restricted to finding crops and irrigation systems that were commercially viable.

In contrast, irrigation development in northern Australia can be characterised as a multi-faceted optimisation problem where there is limited information about the consequences of different resource allocations, challenges in choosing between them because of exclusivity characteristics, and high costs of addressing information gaps. As an example, farmers require long-term water rights to justify crop trials and infrastructure development, but risks of potential environmental

impacts and questions about how to involve Traditional Owners in resource allocations tend to favour shorter-term leases and constrained property rights. The outcome is a type of three-sided Prisoners Dilemma, where the interests of agriculture, environment or Traditional Owners can't be individually satisfied without impacting on other sectors.

To achieve sustainable agricultural developments, policies should be balanced, including balancing economic growth with environmental preservation, managing ecological risks in agricultural systems, and developing sustainable farming systems (Bennett 2008). The National Water Initiative has been designed to achieve these compromises (Australian Government, 2004). Clear objectives are required regarding property rights for water, environmental planning and protections along with more recently First Nations Peoples water rights. Game theory through the Prisoners Dilemma can be applied in this context to describe how farmers and policymakers must cooperate to achieve long-term sustainability, despite short-term individual incentives that might undermine collective goals (see box insert).

There have been a wide range of reviews of requirements for agricultural development in the north, focusing on supply chains, productivity, and policies (Ash et al., 2015; Ash et al., 2017a; Ash and Watson, 2018). Landholder perspectives have not been well captured in past studies, in this report, we aim to understand the ground-level challenges for agricultural development across two jurisdictions: the Ord Irrigation Area in Western Australia and the Northern Territory, specifically the Douglas Daly and Katherine area. The Ord Irrigation Area was developed in the 1960s; however, it faces challenges in agricultural development as the project seeks to increase its footprint in the Northern Territory. The Douglas Daly is a development in its infancy to the south of where the Ord development will cross; however, it faces the same challenges as the Ord Irrigation Area.

Growers, suppliers, and contractors were interviewed and provided their experience and insights into how water-driven development through irrigation was occurring through water frameworks, land resources, supply chain and logistics, human capital, and markets. For this report an overview of the two irrigation areas will be first provided, be followed by the methods and then analysis of the results.

PRISONERS DILEMMA

In the Prisoner's Dilemma two partners in crime or suspects have been put in prison by police and face questioning. The police do not have sufficient conviction evidence and so have separated the suspects to prevent them communicating. The suspects are given an incentive to cooperate with the police. Each prisoner has the option of confessing or remaining silent. If one prisoner confesses while the other remains silent, the betrayer will get a reward and goes free and the silent prisoner is convicted and sentenced based on the other prisoner's evidence. In this case, the silent prisoner should stay in jail for a long period because of the crime and his non-cooperative behaviour.

If both prisoners remain silent and do not confess, they will be released after a short time because of insufficient evidence for conviction. However, if both parties confess they both serve sentences. In the latter case, the period each prisoner stays in jail is shorter than the case in which one prisoner should go to jail because of remaining silent while the other prisoner confesses. The fundamental prisoner's dilemma is whether to trust the silence of his colleague or to trust the reduced sentence the police offer from betraying his colleague.

Source: Per Olov Johansson - An Introduction to Modern Welfare Economics

3.3 Northern Australia

Northern Australia is defined as above the Tropic of Capricorn, and there are a number of irrigation developments occurring in the region. For this study, we focused on the Douglas Daly and the Ord Irrigation Area.

3.3.1 Douglas Daly region (Northern Territory)

The Douglas Daly region is located between Darwin (approximately 200km to the North) and Katherine (200km to the south). Agriculture in the region is developing and in the infancy stages of an agricultural development area. It does not have physical dammed infrastructure to supply water to agriculture but rather is a groundwater-fed system. This means that agriculture can be much more dispersed than for supplemented schemes. The Water Act 1992 states the region falls under the Daly Roper Beetaloo Water Control District which has management of surface and sub-surface water. The Douglas Daly development area falls under the Oolloo Dolostone Aquifer Water Allocation Plan 2019 – 2029 (Water Resources Division, 2019) which is divided into three sections, Northern, Central and Southern (Figure 3.1).

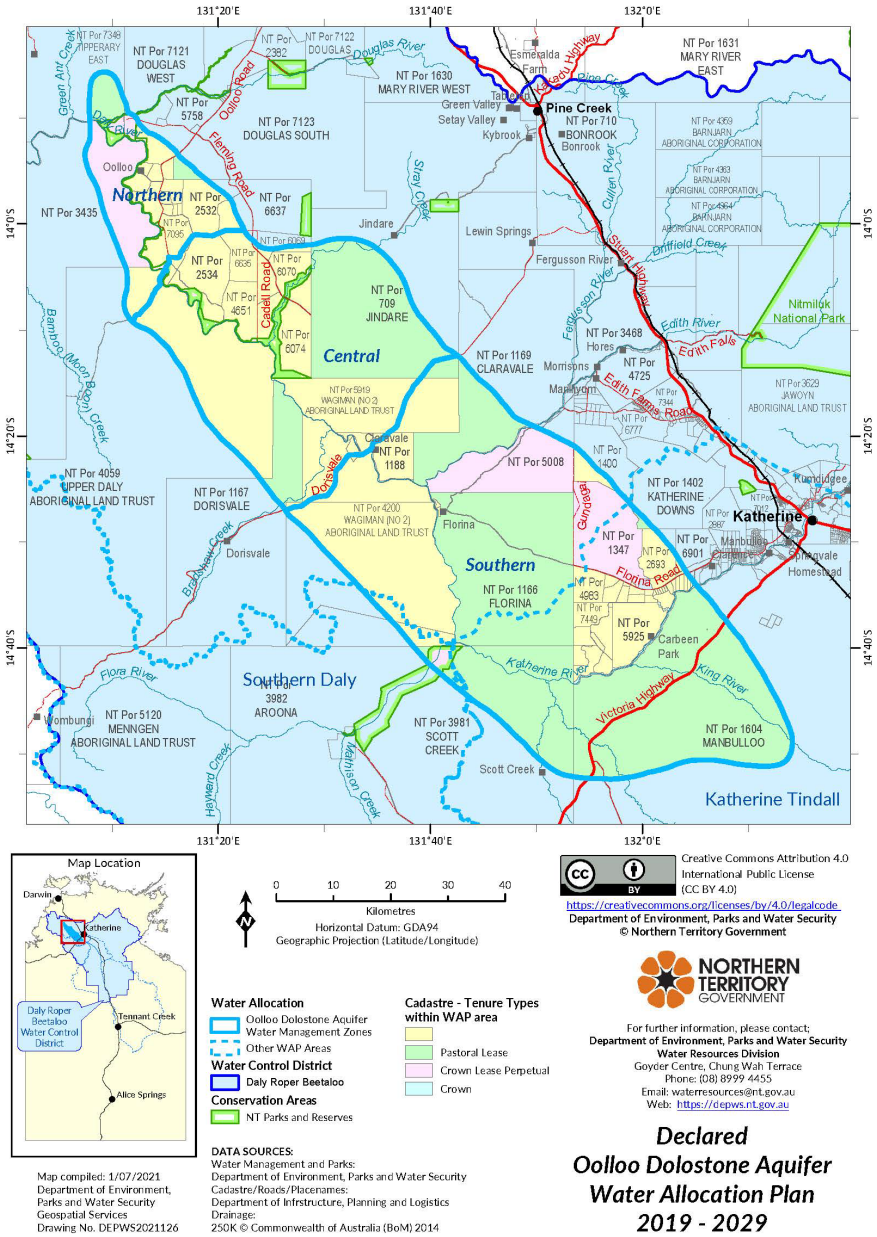


Figure 3.1. The Water Allocation Plan area in the Douglas-Daly region. Source: Water Resources Division (2019)

The Northern Territory Water Planning Allocation Framework (NT Government, 2020) notes that for the top third of the state, at least 80 per cent of annual recharge for river systems is allocated as water for environmental and other public benefit water provision, and extraction for consumptive uses will not exceed the threshold level equivalent to 20 per cent of annual recharge. For aquifers in the event that current and/or projected consumptive use exceeds the 20 per cent threshold level, new groundwater licences will not be granted unless supported by either directly related scientific research into groundwater dependent ecosystem/ cultural requirements, or in the absence of such research, hydrological modelling confirming that total groundwater discharge will not be reduced by more than 20 per cent. There is also a policy for strategic Aboriginal Water Reserves (Northern Territory Government, 2017).

Although the region is in the early stages of commercial development, the Douglas Daly Research Farm (DDRF) facility was established in the 1960s to investigate and research the development and extension of agriculture in the Top End. Early research in the area was focused on peanuts and cotton as potential crops to grow in the Katherine–Daly basin. Various crops followed such as sorghum, safflower, guar, soybean, maize and sesame as well as introduced pasture species sown into cleared and non-cleared areas. Cattle management, breeding, nutrition, market requirements, grazing and carrying capacity trials have been assessed over the years to identify.

Landholders in the Douglas Daly are spatially dispersed with cattle, cropping, cotton, sandalwood, and mahogany forestry, all largely relying on groundwater. Capital required for infrastructure is financed by the landholder, unlike dam infrastructure projects such as the Ord. Landholders in the Douglas Daly and Katherine are also the first generation of cropping pioneers with horticulture more established over a longer time frame.

3.3.2 Ord River Irrigation Area (Western Australia)

The Ord Irrigation area was initially developed in the 1960s. Lake Argyle was created in 1972 to support irrigation expansion and is the largest freshwater storage on mainland Australia. Its storage capacity is 10 760 million cubic meters. Lake Argyle was formed where the Ord River enters the Carr-Boyd Ranges, 40 kilometres south of Kununurra.

Development of the Ord River Irrigation Scheme was initially planned to proceed in two stages. Ord River Irrigation Area Stage 1 (ORIA Stage 1) of the development was completed by 1966: this involved construction of the Kununurra Diversion Dam to form Lake Kununurra, as well as irrigation infrastructure and associated works, and the township of Kununurra (Figure 3.2). By this time, thirty-one farms had been allocated on the Ivanhoe Plain, all irrigated from Lake Kununurra. A further 2,000 ha of land were also developed in 1974 on the Packsaddle Plain. About 14,000 ha are currently developed as irrigated farms (Figure 3.2).

The aim of the Ord Stage 2 expansion was to deliver water and road infrastructure to service about 8,000ha of land at Goomig, subdivision and sale of the 8,000 ha in up to 25 lots, scoping for land at Mantinea (4,000 ha), Ord West Bank (1,300 ha) and Packsaddle (1,380 ha), and work to consider land at Knox (8,000ha), Victoria Highway, Carlton Hill, Bonaparte Plain and the Keep River Plain (NT).

The plan for the Goomig (Weeber Plain) (Stage 2) irrigation expansion was to provide just over 8,000ha subdivided into up to 25 lots, sold and ready for farming by 2012. Efforts to sell land in multiple small freehold titles, initiated in late 2011, did not succeed because not enough proponents met the State's criteria. The State then moved towards seeking a single developer, with Kimberley Agricultural Investment Pty Ltd (KAI) appointed after a competitive tendering process in 2017. The Knox farmlands development near Kununurra was announced in 2024 with a 5,400-hectare lease agreement, granted to KAI.

The third stage of development for the Ord is the Keep River Plains in the Northern Territory which has soils which are well-drained and could support agriculture throughout the wet season. Dry season irrigation water however would come from the Ord. In late 2021 the AAM Investment Group (AAMIG) was announced as the preferred proponent to develop the 67,500-hectare parcel of land.

Cockatoo Sands in Bonaparte, Terrrara and Victoria highway have free draining soils which have been identified as better suited to horticulture than soils at Kununurra. Approximately 6,500 ha of Cockatoo Sands and about 2,400 ha of Pago Sands on Carlton Hill Station suitable for fodder or perennial crops. This area is known as the Bonaparte Plains. Due to the time period of land releases, there is a mix of first and second-generation businesses operating across the ORIA.

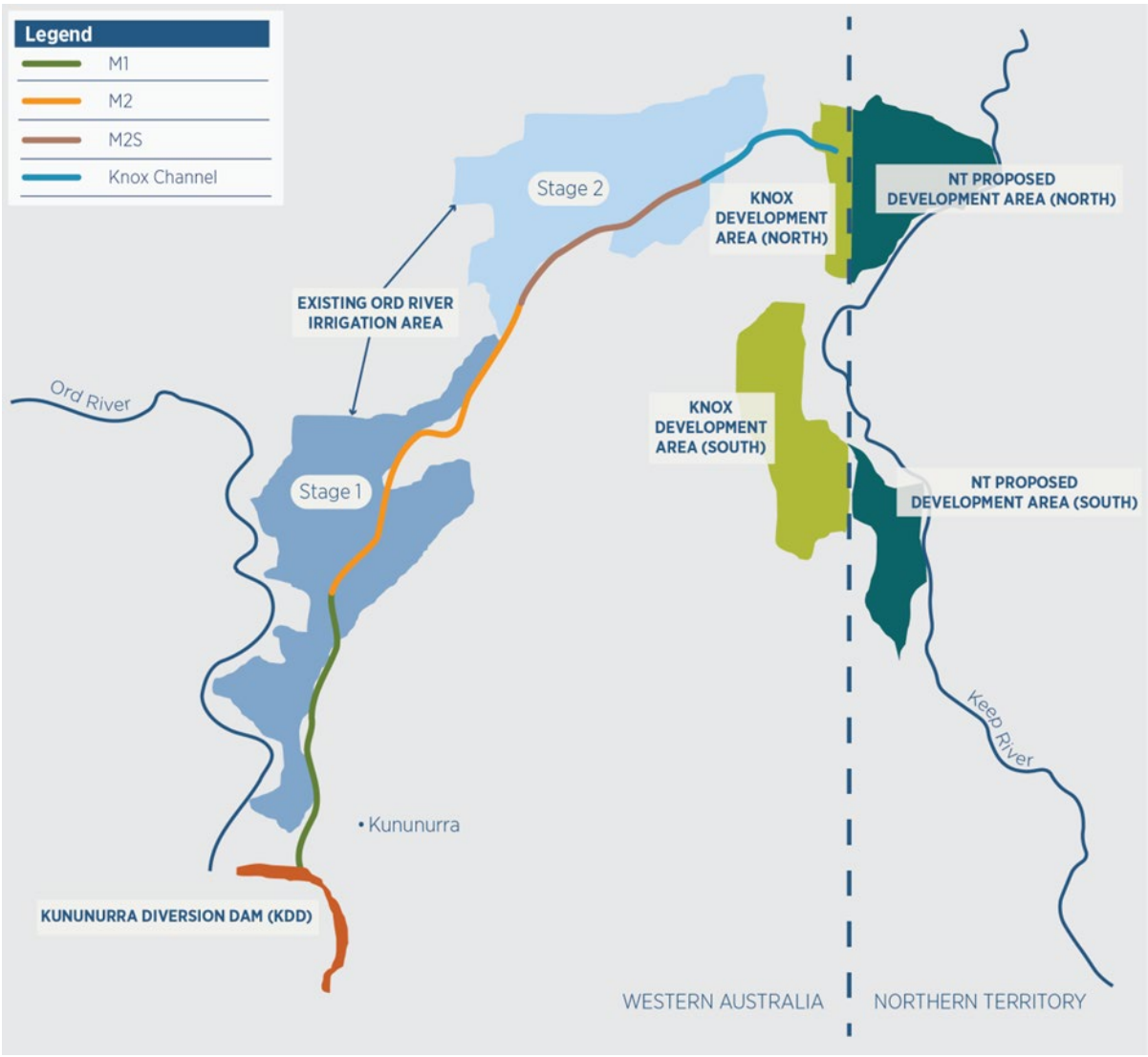


Figure 3.2. Ord River Irrigation Developed Areas and Proposed Development Areas (Department of Primary Industries and Regional Development, 2024)

3.4 Conceptual framework for irrigated agricultural systems

Agricultural development goals such as establishing irrigation schemes with supporting policies can result in landholders having clear and aligned incentives; the opposite is also the case (Potts and Kastelle, 2017). At a governance level it is has been argued that given the Commonwealth National Water initiative there is more coordination and proposed the development of a Northern Australian Water Act (Hart et al., 2020). The governance arrangements associated with development are often complex, with approval systems for many major projects requiring a collaborative philosophy to be successful. Regular staff changes and inconsistent decision-making by approval bodies sends mixed signals to landholders without economic or environmental gains (Dale, 2014).

To achieve sustainable agricultural development, government policies should be balanced, including balancing economic growth with environmental preservation (Campbell, 1962; Bennett,

2008). Policies promoting agricultural development are required to consider the critical factors for landholders to invest and trial various crops, markets, supply chains, water entitlements and supply, and human capital.

3.4.1 Key factors to consider

While access to affordable water is essential for new irrigation developments, it is not the only critical factor. Access to markets, supporting infrastructure and policy settings, cost-effective supply chains and access to human capital are also essential (Ash et al., 2017a; Ash and Watson, 2018) (Figure 3.3). In addition, the mix of climate, soils and water at specific locations, the risk of pests and diseases, particularly in tropical climates, and access to capital can also be significant. New developments face additional approval and compliance requirements to satisfy conditions around water, environmental, and First Nations policy settings, which can add considerable cost and time to developments.

Supply chains and associated transport logistics and infrastructure such as roads and ports, processing facilities and power can present significant barriers for development, increasing costs significantly and undercutting the economic viability of production (Ash et al., 2017b).

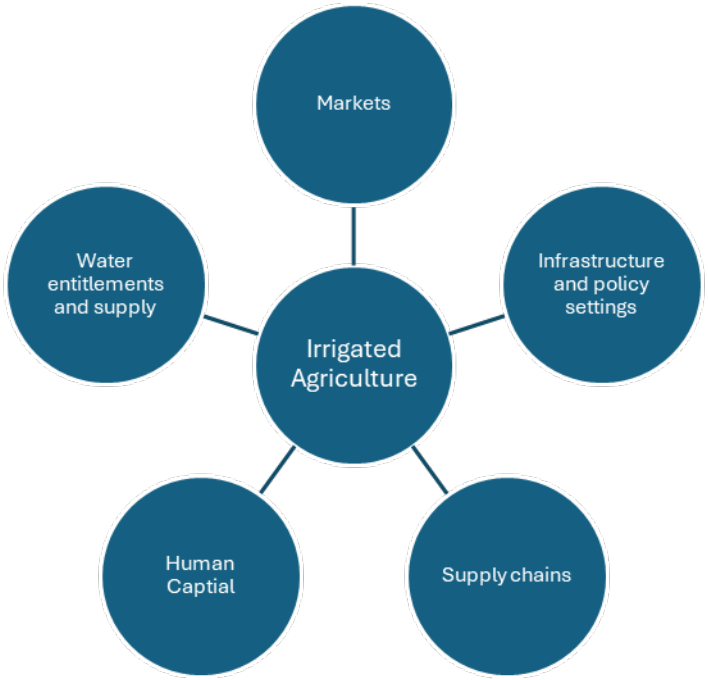


Figure 3.3. Simplified diagram of essential inputs into irrigated agriculture based on the principles of: Ash (2017, 2017b), and Ash and Watson (2018).

3.4.2 Development stages in irrigated agricultural systems

Existing irrigation systems in southern Australia already have established input systems that map to the key dimensions in Figure 3.4. The challenge for greenfield systems is to coordinate the provision of these key elements. In reality, most irrigation systems grow organically from initial trials of pioneer growers or researchers through to mature irrigation districts. In the following analysis, time frames, infrastructure, production, and productivity improvements are considered to group developments into four stages of (1) Pioneer, (2) Innovation, (3) Commercial, and (4) Transformation.

In terms of application to the case studies of interest, the hypothesis is that irrigation in the Douglas Daly region is largely in the Pioneer stage, potentially transitioning into the Innovation

stage, whereas the Ord Irrigation District is in the Innovation stage, transitioning into Commercial Reality (Figure 3.4). By way of comparison, irrigation in the Murray-Darling Basin can largely be categorised in the mature Transformation stage with high and stable values of outputs and long time periods since establishment.

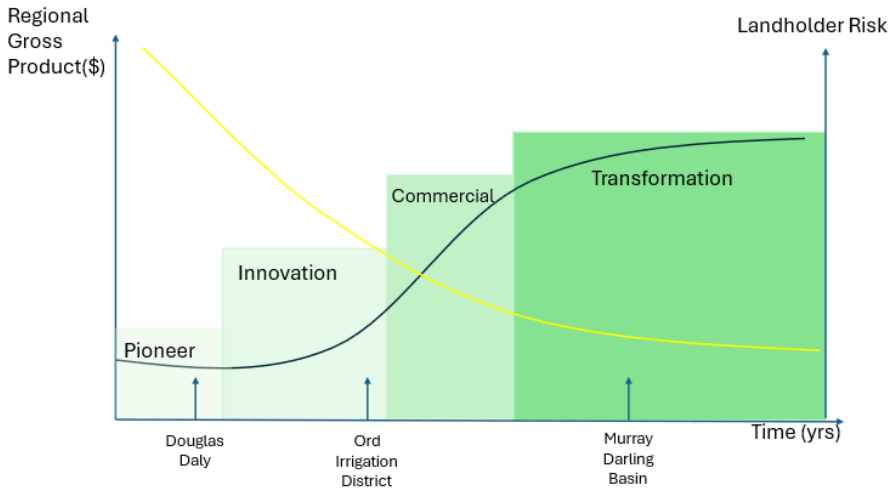


Figure 3.4. Simplified diagram of development stages in irrigated agriculture

3.4.3 Pioneer

A Pioneer stage of development typically involves limited information about crops and commercial viability, limited and/or costly access to water, and constraints over market access and factor inputs. Success usually requires a cohort of innovative and entrepreneurial growers on the one hand, and supportive government and service providers on the other. An element of cooperative behaviour is required to avoid prisoner dilemma-type holdouts. Identification and adoption of new crops and practices would benefit everyone, but without appropriate policy support, each faces disincentives to move first (Height et al., 2022; Campbell et al., 2023; Schrader et al., 2024). Pioneer growers incur full costs and risks individually while benefits are often diffused or delayed (Ostrom, 2002). Poor property rights, including short tenure of water licences exacerbate the prisoner's dilemma as the risk is high for individuals investing in irrigation ventures (Potts and Kastelle, 2017).

Governments often invest resources to reduce risks for pioneer growers, for example by investing in soil mapping, crop research stations and training of agronomists (Hunt et al., 2014; Roxburgh and Pratley, 2015). There are public good benefits from providing better information that reduce the risks of agricultural experiments and innovation. Governments may also improve policy settings around key inputs, often through making land titles suitable for farming enterprises, and mapping water resources and making them available through licenses.

3.4.4 Innovation

The Innovation stage often characterises newer irrigation districts where land titles and water resources are available. The main tasks at the innovation stage are to establish the operating rules for water supply systems and to trial crops and production systems that may be suitable for the geographic location. This stage is often characterised by various patterns of cooperation and collaboration between landholders, either to achieve market access, purchase bulk amount of inputs, or address logistical challenges around tasks such as transport or harvesting. Supply chain

and logistics continue to present barriers, and there is still uncertainty in policy and development, in part because uncertainty about which crops will be commercially viable.

Government normally plays important roles in the innovation stage through policy settings around land and water resources, provision of or support for key infrastructure, and ongoing agronomic trials and support. To be effective, governments should provide clear frameworks and processes across departments to build trust between landholders and government institutions (Marshall et al., 2013; Dare and Evans, 2017).

3.4.5 Commercial Reality

Mature irrigation districts can be characterised as being at the Commercial Reality stage. High-value crop pathways are established, all factor inputs are available and stable markets and supply chains exist. Economies of scale are coordinated through supporting business services or cooperative freight arrangements and collective marketing. The workforce is stable and there is sufficient human capital to ensure that specialists skills are available. There are systems to provide secure titles for both water and land resources, with all water resource allocated and trading markets allow transfer to highest value users. There is little to no government investment in supporting infrastructure or supply chain support.

3.4.6 Transformation

Older irrigation districts often require transformation to remain viable, typically through changes in crop selection, more precise management techniques and greater adoption of agricultural technology. Changes may include shifts to higher value horticultural crops or more intensive production systems, underpinned by extensive local knowledge of production and agronomic conditions. There is greater reliance on business supply chains and vertical integration for sales and inputs rather than cooperative models. Research and development still occur but are usually funded by landholders and industry and are more focused on higher-value crop options and productivity improvements.

3.5 Methods

To identify how the models of essential inputs and development stages might map across to the two case study regions of focus, the viewpoints of irrigators and farmers in each region were sought. This is with a particular focus on the security of water supplies as an essential input into development prospects. While other aspects of supply chain inputs and outputs were discussed with landholders, water security was of particular interest because of differences in titles, access and conditions across Northern Australia, and the key role that this might have on development scenarios.

Semi-structured interviews were conducted with landholders using a conversational approach that allowed for flexible, in-depth discussions while ensuring consistency across key topics. Each interview was guided by five thematic areas regarding agricultural development central to irrigation development: water entitlement and supply, markets, human capital, supply chains and infrastructure and policy settings.

This provided a framework for discussion, though the order and depth of exploration varied according to each participant's responses, expertise and experiences. This conversational method encouraged landholders to share their perspectives and experiences in their own terms, while the interviewer used prompts and follow-up questions to ensure all five areas were adequately covered.

The semi-structured format balanced the need for comparable data across interviews with the flexibility to explore emergent themes and capture the nuanced, context-specific knowledge that

landholders possess about their business operation. Interviews typically lasted between 45 and 90 minutes, allowing sufficient time for rapport-building and detailed discussion of each thematic area.

Interviews were completed in the Ord Irrigation District with six landholders in September 2025, and in early December 2025 in the Douglas Daly and Katherine region with five landholders and an industry representative. The interviews were conducted under an ethics approval granted by Charles Darwin University Australia, number H25002.

To avoid selection bias a snowball approach was used. In Kununurra the Department of Primary Industries and Regional Development sent out an information sheet to their mailing list and interested participants contacted the researcher directly. The interviewer met with the landholders on farm where possible to minimise the impacts to their business given that cotton was being picked at the time of the interview. After the interview, the participant was asked if there was anyone they recommended interviewing. This recommendation was then contacted to request an interview. Interviews with two participants were completed over zoom (online platform) as it was not practical to meet in person.

In Katherine and the Douglas Daly landholders who have been irrigating were cold called and asked if they were interested in participating. The researcher meet with the landholders on farm or in one case in town to avoid inconveniencing them. The interviews were conducted in December 2025 at the start of the wet season and at end of the Mango season. Some potential participants had headed off on a break. More detailed outcomes of the interviews are included in Appendix 1.

3.6 Results

For conciseness, the results of the interview process are summarised into the same five themes discussed with landholders of:

- water entitlement and supply,
- markets,
- human capital,
- supply chains and
- infrastructure and policy settings

3.6.1 Water entitlements and supply

In the Northern Territory the Water Act 1992 provides the framework under which Water Allocation plans and licenses are issued. The Oolloo Dolostone Aquifer Water Allocation Plan 2019 – 2029 is in place for the Douglas Daly which divides the aquifer into three regions: the north, central and southern zones. There are 42 groundwater extraction licenses allocated for agriculture usage across those zones1 The northern zone was declared over-allocated by 990ML at the time the allocation plan was developed. Not all water has been allocated in the other zones, with the central zone being 18,837 ML and the southern zone being 5,059ML under their respective allocation caps (Table 2.1). Of the 42 licenses issued, three are allocated to NT Land Corporation, approximately 13 to forestry (Sandalwood and Mahogony), 10 to horticulture and 25 to other cropping or mixed operations such as hay, pasture, cotton. A number of entities hold more than

[1] Water Licences in the Northern Territory Department of Lands, Planning and Environment, NT Government https://ntg.maps.arcgis.com/apps/dashboards/0ec71b3d7e774e64b43403421170851.

one license with only 27 unique licensees across all industries. There has been only one trade of water entitlement that has occurred.

Table 3.1. Oolloo Dolostone Aquifer entitlements

Water management zone	Estimated sustainable yield (ML/year)	Estimated rural stock and domestic use (ML/year)	Existing entitlements (ML/year)
Southern	29800	946	23795
Central	36378	402	17139
Northern	30700	204	31466
Total	97300	1552	72400

The interviews with landholders revealed that problems with tenure were limiting investment opportunities. The water licence tenure under the allocation plan is for a 10-year period with a review at five years to demonstrate that they are utilising the water. This contrasts with the system in southern Australia where licences have been replaced with water entitlements that provide a secure property right and long-term certainty. The 10-year time frame is to align with the conditions of the overarching Water Act 1992 for reviewing allocation plans.

In interviews landholders were unsure of the five-year review process and what was required to demonstrate they were utilising the water. It was repeatedly stated that the short tenure (ten years with a review at five years) meant that licenses could not be leveraged to finance water infrastructure development, such as bores and pivots. The cost for landholders to equip a bore and pivot was from $600,000 to $1m without considering operating costs. The time required for landholders to source finance and complete the development may exceed the licence period. The short time frame of 10 years precludes property rights for landholders to invest or use the licence as equity in obtaining capital from the banking sector.

While landholders were aware of the Recovery of Unused License Water Entitlements policy, which requires that water licensees using less than 70% of the entitlement for three consecutive years, have to provide evidence of progress against a proposed development plan, water use plan or other relevant plans, they were unsure how this operated in practice. Landholders who had experienced difficulties in obtaining and installation of water infrastructure, such as one who had failed to sink a viable bore in the Katherine aquifer, were unsure if paid receipts and hydrology reports would be sufficient to demonstrate their attempts and continued efforts to utilise the water.

For those who were renewing their licences in the next couple of years there was uncertainty regarding the process, with a lack of communication regarding what was required from the landholders to ensure that the water licence would be re-issued. Landholders were also uncertain about the tenure of water and the capacity of the government to make policy decisions in a short time period with limited consultation.

Participants explained that the ideal outcomes of the review process under the current policy should be that water licences would be re-issued in good faith at the end of the entitlement period. This did not end up being the case for some landholders and legal challenges were entered into to obtain the previous cumulative (medium and high license volume) water licence quantity. Landholders viewed reductions in the volume of licences or changes of level of security as increasing the risk of investments in developing land further.

Strong property rights around water entitlements encourage investment (Wheeler 2001). Currently, there is a prisoners dilemma situation where landholders need certainty over water entitlements to justify investment in the high capital costs of infrastructure (bores, pumping systems, irrigation setup), whereas the government are maintaining a review process to guard against underutilisation or over-extraction. Landholders are in the situation where the existing policy settings conflicts both with their own long-term interests and the government's stated objectives of agricultural development.

Under the 2021 Regulatory Efficiency Program from the Department of Environment, Parks and Water Security, the Department has been implementing efficiencies to improve processing times on water extraction licence applications (NT Department of Environment Parks and Water Security, 2002). Two which are relevant state: (1) The Minister has declared special circumstances for granting public water supply licences and renewal of compliant licences for periods up to 30 years, and (2) The Controller may determine if special circumstances justify granting a licence for longer than 10 years (NT Department of Environment Parks and Water Security, 2002). However, it is not known what special circumstances are sufficient to justify an approval under these conditions.

3.6.1.1 The Ord Irrigation Area

The Ord Irrigation area has 80 registered water licences from the Main Ord River Surface Water Resource. There are however three dominant water licences, Water Corporation, Ord Irrigation Co-operative Limited (OIC, 335,000 ML) and Kimberly Agricultural Investments (KAI, 100,000 ML).

In addition to holding a Surface Water Licence under the RIWI Act (Licence 3), OIC also holds a water service provider licence (Water Services Licence 37) (WL37) issued by the Economic Regulation Authority under s 11 of the Water Services Act 2012 (WA) (WS Act), which authorises OIC to provide non-potable water supply and irrigation services within its operating area.

OIC's operations cover 15,150 hectares of agricultural land with an extensive network of over 300km of irrigation channels and drains. Most of the water diverted by OIC under Licence 3 is diverted to Ivanhoe Plain to the north and about 10% - 12% is diverted at the Packsaddle Pump Station for conveyance to Packsaddle Plain to the south. OIC supplies water to approximately 99 member properties and 11 non-member properties in Ord Stage 1. Under OIC's Rules, OIC members are entitled to an allocation of water as determined by the OIC Board, which has been set at 17 megalitres (ML) per hectare (at the farm gate) since 1996. OIC's non-member customers are landowners whose properties are too small to entitle them to become members of OIC. The non-member customers are required to purchase 12 ML of water per hectare annually, whether they use the water or not. The licence to divert water is re-negotiated every 10 years. There is no certainty that members will receive the same amount of water as previous periods. Members cannot trade all their water "away" from their farm. A minimum of 12 ML/ha must always remain as per the articles of association. For Stage 2 of the Ord development 15 ML per hectare is allocated.

Water is gravity fed by OIC through an open channel system to its members and non-member customers. In 2025 the OIC expansion of operating area to include Knox Creek Plain was approved.

OIC pays a bulk water charge to Water Corporation for the full volume of its annual water entitlement (335 GL128), irrespective of whether OIC uses all of its allocation. As at September 2019, the cost of water to OIC is $1.47 per ML. OIC members pay OIC for water by means of a fixed service charge, a volumetric charge, an OIAMC asset levy, and a pumping surcharge, plus any additional levies. Currently, these charges equate to approximately $400 per irrigated hectare (plus additional levies). OIC continues to invest in the irrigation infrastructure and after spending

$4.05 million to improve efficiencies, OIC achieved distribution efficiency from 56% in 2007 to an average of 76% over the 10 years from 2009 to 2018.

The WA Department of Water and Environmental Regulation has adopted and published a policy Section 5C licence tenure (February 2015). This document is described in its text as a 'standard' and states: Implement a 10-year tenure for licences granted under [s] 5C of the [RIWI Act][.] The standard applies to areas where licensed water entitlements are greater than 30%, but less than 70%, of the approved sustainable limit. In areas where licensed water entitlements are greater than 30% but less than 70% of the approved sustainable limit, the Department:
• will not actively pursue the recovery of unused entitlements; and
• will not require licensees to establish extenuating circumstances as to why the approved development has not been implemented and the licensed water entitlement not fully utilised.

In 2000 the WA Department of Water and Environmental sought to enact that OIC had not been utilising their licence sufficiently and to reduce its volume of water at renewal (State Administrative Tribunal, 2020). However, the OIC took the Department to the State Administration Tribunal and successfully challenged this, maintaining renewal of the full volume of 335GL. The key argument made by OIC was its need to be flexible to meet different markets of which have not stabilised yet, the potential for double cropping cotton, maize and the increase in quantity of hay been produced (State Administrative Tribunal, 2020). According to the current water register the OIC licence now expires in 20230 and KAI license expires in 2029.

Although irrigators in the Ord are effectively under 10-year licences, participants in the interviews were not concerned with the current water licensing arrangements. Some noted they would like to re-design how water is delivered to their property as cotton particularly needs water in specific time window relative to plant growth but the current scheme is set up to water only 25% of the scheme at once. Some landholders discussed installing recycle pits where they could then re-circulate the water on their property to ensure they could meet the plant requirements in the specified window.

Landholders were sceptical regarding the speed at which government plans for development were occurring, and did not foresee that water would be fully allocated in the near future. A number of participants noted they had successfully tendered for land some as long as 10 years ago however there was not co-ordination between State Government Departments to progress the development in that time period. They perceived little risk in availability or security of water in the short to medium term.

3.6.2 Infrastructure and Policy Settings

Ensuring correct policy settings and supporting infrastructure allows developments to be viable, but settings may need to change over time as development progresses. Secure access to land titles and property rights are an underlying enabler of an agricultural industry. Identifying how land is made available to agriculture and any constraints or conditions is important to understand how this might influence entrepreneurship and development opportunities.

3.6.2.1 Douglas Daly

Broadacre landholders in the Douglas Daly who were interviewed had trialled a number of crops with varying degrees of success. Some had experienced soil and biophysical challenges with consecutive cropping but had not devised a successful on-going crop rotation pattern. A number of landholders had switched to lower value fodder crops to supply the cattle industry as the market was close and reliable. One participant was seeking to grow and develop a niche product for the cattle industry.

The forestry industry had previously invested in the region, but there was a significant downturn recently in the area, with Quintis (a large sandalwood company in the area) going into administration. Landholdings are now being sold and converted to horticulture (Matt Bran, 2024). Some landholders had leased land to Quintis to grow sandalwood trees and were now experiencing leases being broken, although sandalwood was not yet at the harvesting stage.

Cotton had been grown for consecutive years by some participants however viability was very low even though a cotton gin had opened in Katherine (previously all raw cotton was trucked to southern Queensland for ginning). There are still large agronomic challenges in finding suitable crops, with growers trialling melons, cotton, maize, corn, soybeans, mungbeans, fodder, and pasture seed. Some crops have lower water requirements (20% of higher water requirement crops) (Table 3.2), but growers who concentrate on those crops may incur risks that water licences are trimmed at a review period. Double cropping may increase water use and reduce risks of water licence reductions, as well as increasing returns on fixed overheads but it is difficult to identify suitable crop pairings across wet and dry seasons.

Table 3.2. Water requirements for major crops in the Douglas Daly

Potential crop	Approx. Water Use requirement (ML/ha)
Intensive horticulture i.e., Mangoes, Melons	15
Intensive forestry i.e., Sandalwood	8-12
Broadacre crops i.e., Cotton	2.5-5
Fodder i.e., Calvalair	1-3

Currently, landholders are not charged a water use fee per megalitre but are charged administration on licence applications. Landholders however incur the cost of sinking the bore into the ground water and then subsequent equipment and pumping costs. Given challenges to find suitable crops and market access there are limited options for pricing water in the Douglas Daly as there is not a clear production value. This is due to the development area being at the pioneer stage of development.

3.6.2.2 The Ord Irrigation Area

Participants noted that the Ord has limited supply of irrigatable land but sufficient supply of water. The black soils in the region have supported a wide range of crops over time, with growers trailing a broad range of crops to meet different market opportunities and agronomic challenges. The distance to markets and high input costs have required growers to be flexible and proactive to ensure ongoing viability.

The participants who had been approved to or had developed parcels of land noted the complexity of legislative burden (Table 3.3 lists relevant legislation) and the lack of co-ordination between Departments to progress it further.

Table 3.3. WA land-based legislation required to be considered in agricultural development and cropping

Western Australia

Aboriginal Heritage Act 1972
Aerial Spraying Control Act 1966
Agricultural and Veterinary Chemicals (WA) Act 1995
Agriculture Act 1988
Conservation and Land Management Act 1984
Environmental Protection Act 1986
Fisheries Resources Management Act 1994
Health Act 1911
Heritage of Western Australia Act 1990
Land Administration Act 1997
Local Government Act 1995
Main Roads Act 1930
Rights in Water and Irrigation Act 1914
Soil and Land Conservation Act 1945
Town Planning and Development Act 1985
Water Agencies (Powers) Act 1984
Water Corporation Act 1995
Water and Rivers Commission Act 1995
Water Services Coordination Act 1995
Waterways Conservation Act 1976
Wildlife Conservation Act 1950

Participants noted they were able and willing to comply with the requirements under each piece of legislation; however, they wanted clear guidelines on how to manage the landscape and development to achieve the desired outcomes.

3.6.3 Markets

3.6.3.1 Douglas Daly

Growers in the Douglas Daly have tried to access a number of markets with varying degrees of success. Limited access to high-value markets means that many growers focus on low-input fodder crops to supply to the cattle industry. There has been substantial interest in growing cotton in the area for fibre and cotton seed meal for cattle feed. The opening of the Katherine cotton gin reduced the freight costs for growers who were previously sending baled cotton to Queensland for processing. However, the cotton price fell in 2025 making it unviable for a number of participants, given that yields are limited by pests, disease and low soil fertility.

The Douglas Daly does have some large horticultural producers supplying existing markets. However, one participant noted that the domestic market for horticulture was at full supply for the timing window which the Douglas Daly could supply, constraining growth prospects. One participant noted that there is no biosecurity program for control or coordinated approach of invasive species, pests and disease and this limits the viability of certain crops to meet the market volume to be viable and the market product specifications.

3.6.3.2 The Ord Irrigation Area

The Ord is an irrigation area that requires high value crops to be grown or for farmers to grow a large volume of crops to be viable. This is because the remote nature of the Ord involves high freight costs for infrastructure, inputs and produce. The distance also makes it challenging to access labour and support systems for infrastructure and agricultural technology. This makes it difficult for local farmers to compete because of the higher overheads and variable costs.

For example, if local farmers wish to compete in the Perth cucurbit market, local farms will need to compete with growers in Carnarvon in Western Australia which is substantially closer to Perth. For this reason, farmers in the Ord tend to move quickly between different crops in order to target crops that have the highest return in a particular season.

Agriculture in the Ord has experienced significant changes over time driven by markets (Figure 3.5) with the region growing horticulture, sugarcane, maize, sandalwood and a diversity of broadacre crops. More recently cotton has become a larger planting with the development of Bollgard 3, and the opening of the cotton gin in 2025. While property sizes in the ORIA (Stage 1) are significantly smaller than in the Stage 2 development, farmers in the ORIA have sought to minimise the costs of transporting farming outputs to markets through the formation of a cooperative.

Participants noted that working together to minimise freight costs contributed to the formation of the ORDCO which is the co-operative which supplies inputs, marketing, warehouse, grain handling and agronomic services. Farmers in the region collectively produced enough maize to charter ships to transport this crop from the Port of Wyndham directly to purchasers in Korea. Collaboration through ORDCO helps to coordinate the production, storage and transportation of maize, but also the use of infrastructure, such as ORDCO warehouses, that had been built and paid for by the farmers.

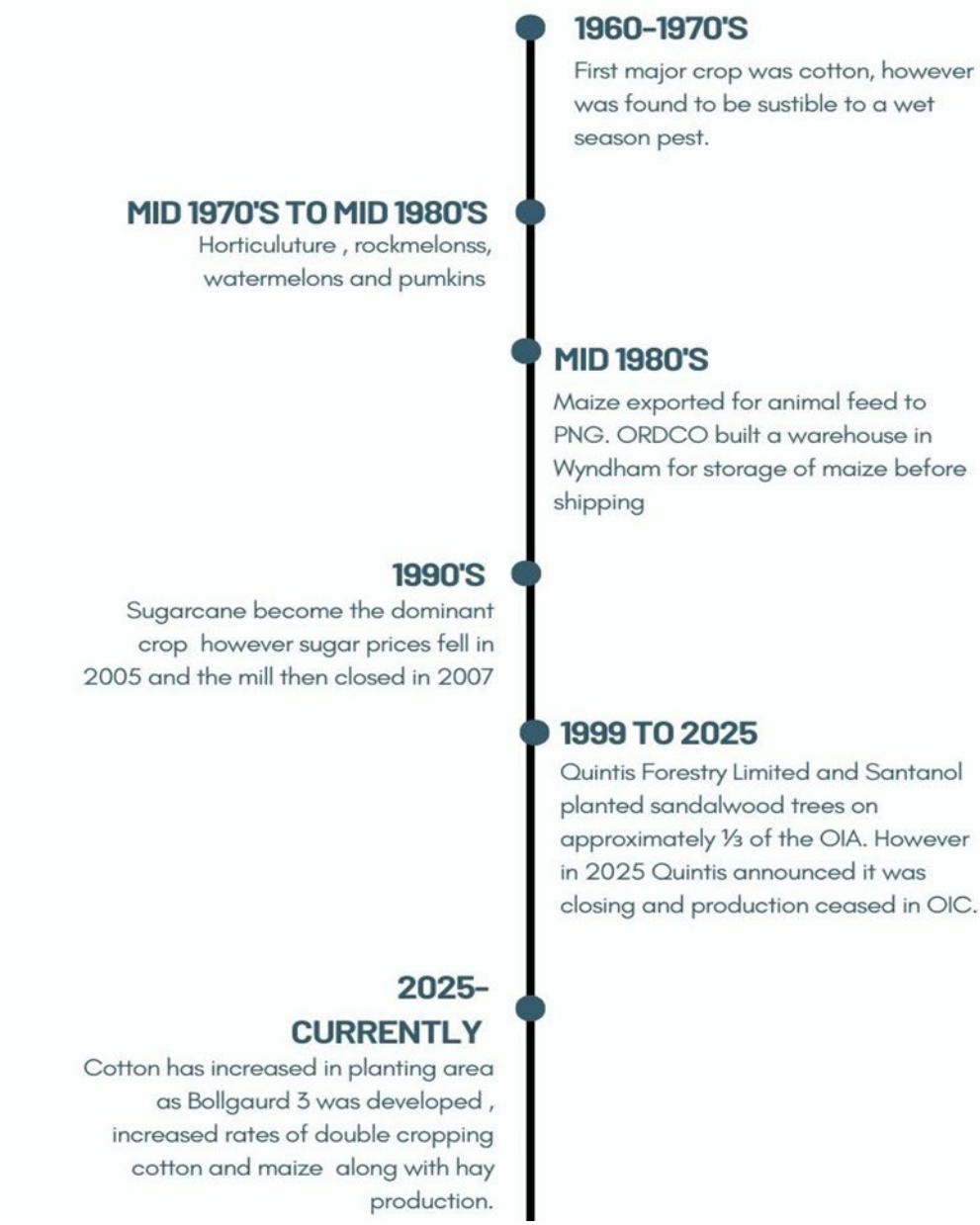


Figure 3.5. Timeline of crops trialled in the Ord Irrigation Area

3.6.4 Supply Chains and Logistics

3.6.4.1 Douglas Daly

Both regions experience high-cost supply chains that impact agricultural margins, however, with differences between regions. Growers from the Douglas Daly experience high freight cost for each tonne of input and each tonne of production. Horticultural growers interviewed in both irrigation areas noted they have key relationships for refrigerated transport to ensure quality and timeliness to market. Growers noted in both areas that this relies on relationships that they have developed over an extended period of time.

3.6.4.2 The Ord Irrigation Area

In the Ord supply chain, logistics is more co-ordinated than in the Douglas Daly (Figure 3.6) with the Ord Irrigation Co-Operative (Figure 3.7) organising logistics to Kununurra. This provides coordination of inputs, supporting grain receival, storage and marketing of products, along with agronomy advice. The co-op also has warehousing capacity at Wyndham Port.

Growers in the Ord region are also in closer proximity to each other. All participants noted the port facility at Wyndham has the potential to be a critical asset in the further development of the OIA. Currently, the lack of a biosecurity officer to assess incoming loads is limiting options for this to be a port of entry. This results in the port not being able to be utilised for bulk fertiliser or inputs. When previous attempts to use the port have occurred it has resulted in the ship being diverted to Fremantle because a biosecurity officer has not been able to attend to allow the release of the product.



Figure 3.6. Douglas Daly Supply Chains and logistics

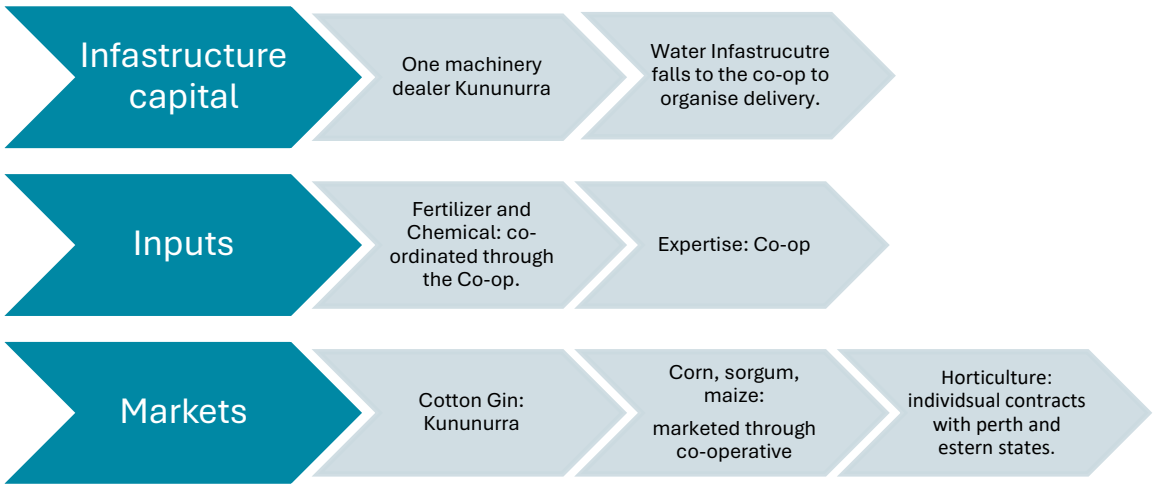


Figure 3.7. The Ord Irrigation Area supply chain and logistics

3.6.5 Human Capital

Both regions noted the importance of accessing labour through overseas working visas with one noting the changes in the hours worked over a period of time made it difficult as the crop went over a longer time period and the hours for consecutive weeks would be higher than the visa permitted. This created problems in having workers at the right time to match the harvest. Another participated noted that the visa although were extremely strict were fair and the same workers from pacific islands came every year allowing them to upskill these workers over a number of years. One participant noted that they were sponsoring a worker from the Netherlands.

Limited tropical pasture agronomy support was identified in the Douglas Daly to support the rotations of tropical pastures but also grown under more intensive conditions. Douglas Daly did note that the increase in cotton had attracted agronomists which have insights into managing mungbeans and other legume crops too. The variety of where technical support was available was identified in each region, with the Douglas Daly seeking support more from Queensland than the Ord region.

ORDCO employing agronomists in their team had mitigated the need for agronomic technical support although still sought parts and repairs from Perth. A number of participants they had good access to staffing with the township of Kununurra close by.

3.7 Conceptual framework for irrigated agricultural systems

Agricultural development goals such as establishing irrigation schemes with supporting policies can result in landholders having clear and aligned incentives; the opposite is also the case (Potts and Kastelle, 2017). At a governance level it is has been argued that given the Commonwealth National Water initiative there is more coordination and development of a Northern Australian Water Act (Hart et al., 2020). The governance arrangements associated with development are complex, with often major project approval systems are opaque collaborative philosophy that drives their operational culture. Regular staff changes and inconsistent decision-making sends mixed signals to landholders without economic or environmental gains (Dale, 2014).

To achieve sustainable agricultural developments government policies should be balanced including balancing economic growth with environmental preservation (Campbell, 1962; Bennett, 2008). The economic policies are required to consider the critical factors for landholders to invest and trial various crops, markets, supply chains, water entitlements and supply and human capital.

3.7.1 Development stages in irrigated agricultural systems

Existing irrigation systems in southern Australia already have established input systems that map to the key dimensions in Figure 3.8. The challenge for greenfield systems is to coordinate the provision of these key elements. In reality, most irrigation systems grow organically from initial trials of pioneer growers or researchers through to mature irrigation districts. In the following analysis, time frames, infrastructure, production and productivity improvements are considered to group developments into four stages of (1) Pioneer, (2) Innovation, (3) Commercial, and (4) Transformation.

In terms of application to the case studies of interest, the hypothesis is that irrigation in the Douglas Daly region is largely in the Pioneer stage, potentially transitioning into the Innovation stage, whereas the Ord Irrigation District is in the Innovation stage, transitioning into Commercial Reality (Figure 3.8). By way of comparison irrigation in the Murray Darling Basin can largely be categorised in the mature Transformation stage with high and stable values of outputs and long time periods since establishment.

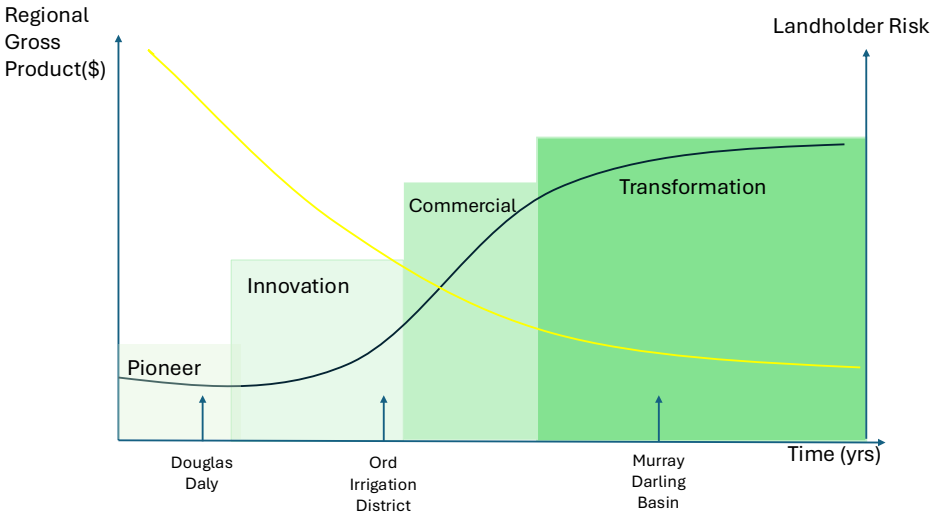


Figure 3.8. Simplified diagram of development stages in irrigated agriculture

3.7.1.1 (a) Pioneer

A Pioneer stage of development typically involves limited information about crops and commercial viability, limited and/or costly access to water, and constraints over market access and factor inputs. Success usually requires a cohort of innovative and entrepreneurial growers on the one hand, and supportive government and service providers on the other. An element of cooperative behaviour is required to avoid prisoner dilemma-type holdouts. Identification and adoption of new crops and practices would benefit everyone, but without appropriate policy support, each faces disincentives to move first (Height et al., 2022; Campbell et al., 2023; Schrader et al., 2024). Pioneer growers incur full costs and risks individually while benefits are often diffused or delayed (Ostrom, 2002). Poor property rights specifically short tenure of water licences exacerbates the prisoners dilemma as the risk is high for individuals investing in irrigation ventures (Potts and Kastelle, 2017).

Governments often invest resources to reduce risks for pioneer growers, for example by investing in soil mapping, crop research stations and training of agronomists (Hunt et al., 2014; Roxburgh and Pratley, 2015). There are public good benefits from providing better information that reduce the risks of agricultural experiments and innovation. Governments may also improve policy settings around key inputs, often through making land titles suitable for farming enterprises, and mapping water resources and making them available through licenses.

3.7.1.2 (b) Innovation

The Innovation stage often characterises newer irrigation districts where land titles and water resources are available. The main tasks at the innovation stage are to establish the operating rules for water supply systems and to trial crops and production systems that may be suitable for the geographic location. This stage is often characterised by various patterns of cooperation and collaboration between landholders, either to achieve market access, purchase bulk amount of inputs, or address logistical challenges around tasks such as transport or harvesting. Supply chain and logistics continue to present barriers, and there is still uncertainty in policy and development, in part because uncertainty about which crops will be commercially viable.

Government normally play important roles in the innovation stage through policy settings around land and water resources, provision of or support for key infrastructure, and ongoing agronomic

trials and support. To be effective governments should provide clear frameworks and processes across departments to build trust between landholders and government institutions (Marshall et al., 2013; Dare and Evans, 2017).

3.7.1.3 (c) Commercial Reality

Mature irrigation districts can be characterised as being at the Commercial Reality stage. High-value crop pathways are established; all factor inputs are available and stable markets and supply chains exist. Economies of scale are coordinated through supporting business services or cooperative freight arrangements and collective marketing. The workforce is stable and there is sufficient human capital to ensure that specialists skills are in close proximity.

There are systems to provide secure titles for both water and land resources, with all water resource allocated and trading markets allow transfer to highest value users. There is little to no government investment in supporting infrastructure or supply chain support.

3.7.1.4 (d) Transformation

Older irrigation districts often require transformation to remain viable, typically through changes in crop selection, more precise management techniques and greater adoption of agricultural technology. Changes may include shifts to higher value horticultural crops or more intensive production systems, underpinned by extensive local knowledge of production and agronomic conditions. There is greater reliance on business supply chains and vertical integration for sales and inputs rather than cooperative models. Research and development still occurs but is usually invested in by landholders and industry and is more focused on higher value crop options and productivity improvements.

3.8 Discussion

Developing Northern Australia for agriculture has critical aspects of land and water policy, markets, supply chain and logistics and human capital to effectively contribute to regional economic development. Landholders interviewed in the Ord and Douglas Daly had varied insights into the progress and development of agriculture in their regions, however each regions have lessons that the other could learn from.

Currently the Douglas Daly is in the pioneer phase of irrigation development. Water planning has occurred and processes for licensing exist. However water governance reform is required creating longer term licencing and stronger property rights to allow investment to occur and mitigate the prisoner's dilemma. For the Douglas Daly the high costs of irrigation infrastructure which is capital a landholder is required to invest before knowing the return on investment is highly risky. Allowing landholders to trial different crops, secure markets and invest in both water infrastructure and farming systems infrastructure. This would support the region to move to the innovation phase of development.

In the Ord landholders also have short licence periods however as the Ord Irrigation Cooperative holds the water licence for its members and the 2020 hearing outcome, they are not concerned with water insecurity. Those who have sought to further develop land for irrigation and have won tenders have been hindered by poor and unclear government process. Clear and transparent government processes that are followed builds trust and growers can invest for long term outcomes. The current demand for water is not exceeding the available land for development and with markets still being developed the flexibility in the water allocation being certain allows trailing niche products, double cropping or new crops.

Each of the regions are sensitive to market prices and input shocks, impacting the viability of the regions. The Ord Irrigation Area cooperative arrangements have been proven advantageous in securing markets and providing warehouse, processing, handling and supply of inputs. This grower

owned cooperative highlights the scope for reducing barriers with cooperation. Although there are a small number of growers in the region, the irrigation cooperative highlights the strength in a central organisation. The capacity to use the Wyndham Port for receivals would further reduce input costs and support the region shifting to a commercial reality that reduces its reliance on government investment.

As the third stage of the Ord is planned, a number of considerations will be required between the two jurisdictions. Between the land and water legislation of the individual states and the supporting markets, supply chains and logistics, and infrastructure. Given that the water source will be the Ord, and there is no water plan in place for the Stage Three Development, there may be a requirement to make special amendments. In 2026, the NWI initiative is also being reviewed and provides a platform to consider if this national policy requires more consideration of northern water systems, such as the Douglas Daly and the Ord Irrigation Area.

3.9 Conclusions

The development of irrigated agriculture across Northern Australia's Ord Irrigation Area and Douglas Daly region reveals that while each area sits at a different stage of maturity, both are shaped by the same fundamental challenge of creating the governance conditions that allow individual growers to invest with confidence rather than retreat into risk-averse behaviour.

The prisoner's dilemma dynamic is present in both regions, though it presents differently. In the Douglas Daly, the pioneer phase of development combined with short-term licensing and weak property rights means that the high upfront capital cost of irrigation infrastructure creates a significant risk for individual landholders who cannot yet see a return on investment. In the Ord, more secure collective water entitlements through the cooperative have largely resolved water insecurity, yet unclear and inconsistent government approvals processes continue to discourage those seeking to expand. The lesson shared across both regions is that where governance frameworks fail to provide certainty, individual actors default to inaction — and the broader regional opportunity is forfeited. Addressing the prisoner's dilemma therefore requires not simply more government investment, but smarter, more transparent and consistently applied policy that shifts the incentive structure toward long-term productive investment.

Cooperative models offer coordination, and the Ord Irrigation Cooperative stands as the most compelling evidence of this in Northern Australia. By holding the water licence on behalf of its members and providing shared access to warehousing, processing, handling and input supply, the different cooperatives has reduced the barriers that would otherwise leave individual growers exposed to market and logistical risk alone. The ability to aggregate volume, secure markets and spread infrastructure costs across a membership base has allowed the Ord to progress toward commercial self-sufficiency in ways that the Douglas Daly, still operating largely through individual landholders, has not yet been able to achieve.

Expanding port access through Wyndham for inward receivals would further strengthen the Ord irrigation are by reducing input costs and increasing the commercial viability of the region. For the Douglas Daly, the cooperative experience of the Ord offers a clear model worth considering as the region seeks to transition from pioneering to innovation demonstrating that the aggregation of grower interests into a central organisation can convert fragile, fragmented supply chains into a functioning commercial system.

Looking forward, the policy environment across Northern Australia is at an inflection point that presents both risk and opportunity. The planned Stage Three expansion of the Ord across two jurisdictions, in the absence of a water plan and requiring navigation of distinct state land and water legislation, will demand a level of intergovernmental coordination and policy discipline that

has historically been difficult to achieve. Simultaneously, the 2026 review of the National Water Initiative offers a timely opportunity to ensure that national water policy is reformed to better reflect the distinct hydrology, tenure arrangements and development dynamics of northern water systems, including both the Ord and the Douglas Daly. If governments use this moment to strengthen property rights, extend licensing tenure periods, clarify approvals processes and invest in the logistics infrastructure that underpins regional supply chains, the conditions for breaking the prisoner's dilemma can be established at scale. Failure to do so risks leaving two regions with significant agricultural potential locked in the same cycle of underinvestment, coordination failure and dependence on government support that has constrained their development to date.

4 Economic and Water Use Analysis of Cotton Production in the Daly River Catchment

Authors: Samy Andres Leyton-Flor and Kamaljit Sangha

4.1 Executive Summary

This project evaluates the economic viability, water-use efficiency, and policy alignment of cotton production in the Daly River Catchment (DRC), with a particular focus on the contrasting performance of irrigated and rainfed systems. The analysis integrates 2025–26 industry gross-margin budgets, 20-year Net Present Value (NPV) modelling, sensitivity testing, Gross Production Water Use Index (GPWUI) estimates, and a review of the region's evolving water-governance framework. Overall, the findings show that cotton can be a viable crop in the DRC, but this viability is largely confined to irrigated systems and depends on development being consistent with environmental safeguards, water-planning limits, and social-licence expectations.

Long-term financial modelling identifies a clear hierarchy of system performance. Furrow-irrigated cotton delivers the strongest financial returns under current assumptions, with a 20-year NPV of approximately AU$10,818/ha and an Equivalent Annual Value (EAV) of about AU$1,021/ha/year at a 7% discount rate. These returns reflect strong annual gross margins relative to moderate capital costs. Overhead (pivot) irrigation also performs well operationally, but its substantially higher upfront capital requirement reduces its 20-year NPV to only about AU$457/ha at the same discount rate, making it financially marginal under baseline assumptions and unprofitable when discount rates rise above 7%. Rainfed cotton performs substantially worse than irrigated systems and is not viable under the standard 7% discount rate scenario, although it can yield a small positive NPV at very low discount rates (3–5%). In practical terms, however, its low and highly variable yields, coupled with climate exposure and limited margin to recover land-development costs, make it a weak stand-alone investment option for the DRC.

A key finding of the report is that the apparent financial strength of furrow irrigation is highly contingent on the current absence of volumetric water pricing in the Northern Territory (NT). The report's sensitivity analysis shows that even modest water charges would materially erode the NPV advantage of furrow systems because of their higher water demand. This makes water policy reform a central determinant of future cotton profitability in the DRC. Overhead irrigation is therefore strategically important not because it currently outperforms furrow irrigation financially, but because it uses less sourced water and is likely to be more resilient under future pricing, compliance, and licence-efficiency requirements.

Water productivity is central to cotton's suitability in the DRC because the catchment supports groundwater-dependent ecosystems and is subject to increasing scrutiny over extraction, monitoring, and licence compliance. On a sourced-water basis, overhead irrigation achieves the highest GPWUI at 1.54 bales/ML, compared with 1.24 bales/ML for furrow irrigation. Rainfed cotton performs much more poorly when total crop water use is considered, returning only about 0.56 bales/ML based on estimated evapotranspiration requirements. These results indicate that while furrow irrigation currently provides the strongest financial returns, overhead irrigation is the most water-efficient system and is better aligned with a future policy environment that rewards measurable water-use efficiency.

The policy and governance context is therefore critical to interpreting the economic results. Cotton development in the DRC occurs within one of the NT's most environmentally and culturally sensitive water-management settings, shaped by instruments such as the Oolloo Dolostone Aquifer Water Allocation Plan and the Territory Water Plan. The "use-it-or-lose-it" approach,

stronger compliance enforcement, tighter metering expectations, and likely future water pricing all increase the importance of irrigation efficiency and transparent reporting. At the same time, current assessments of Northern Territory water governance highlight ongoing weaknesses in Indigenous water rights, transparency in planning, and procedural fairness. As a result, cotton development that does not incorporate robust environmental safeguards, genuine Traditional Owner engagement, and culturally responsive governance is likely to face both regulatory obstacles and social licence risks.

The report also shows that climate and agronomic risk remain major constraints, particularly for rainfed cotton. Rainfed systems are highly exposed to variable wet-season onset, cloud-affected radiation during flowering, hot nights, and short soil-moisture windows, all of which are known to suppress yield in northern Australia. Irrigated systems reduce some of this exposure by allowing greater control over water supply and timing, but they are not risk-free. Heat extremes, pest and disease pressures, soil variability, and the need for precise irrigation scheduling remain significant constraints. These conditions mean that even irrigated cotton must be supported by careful soil selection, robust scheduling tools, heat-avoidance strategies, and integrated pest management.

The findings support a cautious but affirmative conclusion that cotton can form part of the DRC's agricultural future, but only where development is focused on irrigated systems and closely aligned with water-governance rules, sustainable-yield limits, environmental protection, and community expectations. Furrow irrigation currently provides the strongest financial performance, but this advantage may narrow significantly as water pricing is introduced. Overhead irrigation offers the best water-use efficiency and stronger long-term alignment with likely policy conditions. For this reason, the most appropriate pathway for the DRC is not broad rainfed expansion, but targeted, efficient, and well-governed irrigation development on suitable soils and within secure entitlement settings.

4.2 Introduction

This section evaluates the economic viability, water-use efficiency, and policy alignment of cotton production in the Daly River Catchment (DRC), with a particular focus on the contrasting performance of irrigated and rainfed systems. The analysis integrates 2025–26 industry gross-margin budgets, 20-year Net Present Value (NPV) modelling, sensitivity testing, Gross Production Water Use Index (GPWUI) estimates, and a review of the region's evolving water-governance framework. Overall, the findings show that cotton can be a viable crop in the DRC, but this viability is largely confined to irrigated systems and depends on development being consistent with environmental safeguards, water-planning limits, and social-licence expectations.

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4.3 Methods

4.3.1 Literature review

The methodology adopted for this study involved a literature review designed to capture both region-specific agricultural economics and broader insights from cotton production systems in comparable tropical and subtropical environments. The review focused on key variables, including production costs, water-use efficiency, farm-scale economics, and long-term viability under different water-pricing scenarios.

A multi-source strategy ensured comprehensive coverage of relevant literature. Peer-reviewed academic sources were accessed through databases such as Web of Science and Scopus, targeting journals in agricultural economics, water resource management, and tropical agriculture. Grey literature was equally prioritised, with extensive searches of industry and government repositories. Key sources included the Cotton Research and Development Corporation (CRDC) for technical reports and benchmarks, the Cooperative Research Centre for Developing Northern Australia (CRCNA) for water resource and climate adaptation studies, and Ag Econ for economic data and farm surveys. Additional sources were drawn from NTG publications and technical reports from the NT Farmers Association, which provide region-specific economic data.

The review concentrated on Australian cotton production, with a specific focus on Northern Australia's wet–dry tropics, including the DRC, Douglas–Daly region, and Katherine. Southern cotton regions were included only as benchmarks for irrigated systems.

4.3.2 Economic analysis

The economic analysis aims to evaluate the viability of different cotton-growing approaches in the DRC, focusing on cost efficiency, water use, and yield performance under tropical wet–dry conditions. This methodology integrates industry gross-margin budgets, regional agronomic benchmarks, and long-term financial modelling to inform decision-making (Gittinger, 1985).

Key inputs and outputs

The analysis considers three core elements to assess cotton efficiency:

- Input Costs

All variable costs required to produce cotton are identified, including pre-planting operations, machinery, fertiliser, pesticides, energy/fuel, irrigation costs, and other operating expenses. These figures are drawn from industry gross-margin budgets for rain-fed and irrigated systems in northern Australia (Ag Econ, 2025a).

- Water use requirements

Water application volumes (ML/ha) and associated costs are included for irrigated systems, with benchmarks ranging from 5.5 to 8.9 ML/ha, depending on the irrigation method (furrow vs. overhead). Rain-fed systems are assumed to have zero applied irrigation, but remain sensitive to rainfall variability (CottonInfo, 2025).

- Yields and Efficiency

Yield assumptions are based on regional data. Rain-fed cotton ~0.9–1.1 t/ha (≈4–5 bales) and irrigated cotton ~2.3–2.7 t/ha (≈10–12 bales). Efficiency is assessed by comparing gross margins per hectare and cost per bale under different scenarios (Ag Econ, 2025a, 2025g).

4.3.3 Long-term financial horizon

To assess economic viability, the analysis uses a 20-year time frame, reflecting the life cycles of irrigation infrastructure and major equipment. This horizon allows for inclusion of replacement costs, discount rates, and potential changes in input prices and water allocation policies. Net present value (NPV) calculations were applied to compare long-term profitability across systems (Ag Econ, 2025a; CRCNA, 2020).

4.3.4 Evaluation of rain-fed vs irrigated cotton

A core component of this study is the comparative assessment of water application methods and overall crop efficiency for cotton production in the DRC. This analysis integrates agronomic benchmarks, industry budgets, and regional water policy considerations to evaluate the sustainability and economic viability of rain-fed versus irrigated systems. More detailed evidence is provided in Appendix 2.

The feasibility matrix used in this report is based on multi-criteria evaluation (MCE) and multi-criteria decision-making (MCDM) principles, which are widely applied in agricultural systems assessment to evaluate complex decisions involving environmental, social, and economic factors. MCE/MCDM frameworks support structured comparison across multiple criteria by assigning weights or scores to each factor and synthesising these into comparative rankings or feasibility outcomes (Minh, 2024).

The matrix compares rain-fed and irrigated cotton production systems in the DRC across six criteria:

- Economic viability
- Climate risk
- Water security
- Capital investment
- Compliance complexity
- Social license
- Pest and disease risk

Each criterion is scored on a scale of 1 (low) to 3 (high) to reflect relative feasibility, supported by existing literature on cotton production, water demand, climate sensitivity, and sustainability decision-making frameworks. Scoring was descriptive rather than weighted, following MCE practices for qualitative comparisons in early-stage feasibility analysis (Minh, 2024).

This comparative analysis will inform whether pursuing irrigation in the DRC is economically and environmentally sustainable under projected climate and policy scenarios.

4.3.5 Water efficiency

Within the context of the research conducted for the DRC, water use efficiency (WUE) is broadly defined as the optimisation of production per megalitre of water. More specifically, identifying the most "efficient" crop involves determining the optimal balance between inputs and yields to ensure long-term financial and environmental sustainability (Cotton Australia and CRDC, 2024; Cotton Australia and CRDC, 2025a).

The Australian cotton industry utilises specific indices to quantify the balance between resources consumed and lint produced. For this study, the Gross Production Water Use Index (GPWUI) was estimated to compare irrigated with rainfed cotton.

GPWUI is the primary benchmark for comparing performance across different farms, regions, and seasons. It relates total lint production (bales) to the sum of all water inputs, including irrigation, effective rainfall, and used soil moisture (CRDC and CottonInfo, 2025a). GPWUI reflects the

number of cotton bales produced per megalitre (ML) of water applied on the farm, making it a valuable measure of how effectively a farm converts its water resources into potential profit. To calculate GPWUI, the cotton yield in bales per hectare is divided by the total water available to the crop per hectare in ML, yielding a final value expressed as bales per ML. One bale corresponds to 227 kilograms of lint. The total seasonal water supply includes irrigation inputs, effective rainfall during the growing period, and the soil moisture the crop draws upon (McLeod et al., 2024).

$$GPWUI = \frac{cotton\ yield}{total\ water}$$

4.4 Input costs for cotton production in the Daly River Catchment: Rainfed vs irrigated systems

Cotton production involves two distinct systems: rain-fed and irrigated, each with unique cost structures and risk profiles. Understanding the input costs is critical for evaluating economic viability and water allocation strategies under the Daly Water Availability Project.

Rainfed cotton systems dominate the NT landscape, accounting for more than 95% of planted area. These systems rely entirely on wet-season rainfall, eliminating irrigation costs but introducing significant climate risk. The primary cost drivers for rain-fed cotton are crop nutrition and pest management. Fertiliser typically represents the largest share of variable costs, often exceeding 40%, as growers aim to compensate for nutrient leaching in high-rainfall conditions. Machinery operations and fuel for planting and harvest add further expense, while pesticide costs remain modest but essential for managing tropical pest pressures. Based on industry gross-margin budgets, total variable costs for rain-fed cotton in Northern Australia average around AUD 2,400–2,500 per hectare, with indicative lint yields of 0.9–1.1 tonnes per hectare (≈4–5 bales). These figures translate to a cost of roughly AUD 600 per bale, underscoring the narrow margins and high sensitivity to seasonal rainfall and radiation deficits during flowering (Ag Econ, 2025e, 2025g).

In contrast, irrigated cotton systems, though representing less than 5% of total growing area in the NT (NT Farmers Association, 2020), offer higher yield potential and more predictable returns, provided water access and infrastructure are secured (Ag Econ, 2025d; CottonInfo, 2025). Furrow-irrigated cotton budgets for northern Australia assume yields of 2.5 tonnes per hectare (≈11 bales), supported by 8.6 ML/ha of applied water (Ag Econ, 2025d). Total variable costs in these systems average AUD 4,800 per hectare, with fertiliser and machinery remaining significant cost components, but irrigation-related expenses (water charges, pumping, and maintenance) adding complexity (Ag Econ, 2025d). Overhead irrigation systems, such as centre pivots, reduce water volumes to 5.5–6.7 ML/ha but increase energy costs due to pumping requirements. These systems typically incur variable costs of AU$4,300–4,400 per hectare, with gross margins exceeding AU$2,400 per hectare under favourable conditions (Ag Econ, 2025f).

For the DRC, these cost structures have practical implications. Rainfed systems align with the region's wet-season rainfall pattern and minimise capital outlay, but they expose growers to high climate risk and yield variability. Irrigated systems, while offering superior productivity and profitability, depend on reliable water allocations and infrastructure investment, raising questions about long-term sustainability and competing water demands. Decision-makers must weigh these trade-offs when modelling economic outcomes and setting policy for water entitlements, particularly under scenarios of climate variability and Indigenous water reserve commitments (CRCNA, 2020; CottonInfo, 2025).

Based on the 2025-26 industry gross margin budgets and regional economic reports, Table 4.1 compares the variable production costs for the three primary cotton systems.

Table 4.1. Annual gross margin budget for rainfed and irrigated cotton production systems in the Daly River Catchment, based on 2025–26 industry benchmarks.

Metric	Furrow irrigation (Ord River)	Overhead irrigation (Pivot)	Rainfed (Single skip)
Yield (bales/ha)	11.0	10.3	3.6
Total Gross Income (AU$/ha)	7,237	6,777	2,325
Variable Costs (AU$/ha)			
Nutrition (fertiliser)	1,244	887	71
Crop protection and licenses	782	884	475
Irrigation (water and energy)	98	836	0
Picking, cartage and ginning	2,074	1,157	495
Other (planting, fallow, ins.)	602	610	440
Total variable costs (AU$/ha)	4,800	4,374	1,481
Annual Gross Margin (AU$/ha)	2,437	2,403	844
Sourced water (ML/ha)	8.9	6.7	0

Note: Bales calculated using 227 kg per bale; figures sourced from Ag Econ (2025d, 2025f, 2025g). Rainfed (single skip) refers to a planting configuration in which two rows are planted, leaving the third row unplanted, reducing plant density to manage moisture stress and production risk under rainfall-dependent conditions. Figures represent seasonal operating costs and returns per hectare only. Capital expenditure and time value of money are excluded.

4.5 Long-term costing analysis

The following 20-year NPV analysis and sensitivity assessment for cotton production in the Daly catchment are based on current gross margin (GM) budgets, estimated development costs, and projected water management policies.

4.5.1 20-year Net Present Value analysis

The 20-year Net Present Value (NPV) analysis was undertaken to evaluate the long-term financial viability of three cotton production systems: irrigated furrow, irrigated overhead (pivot), and rainfed single skip. The evaluation uses a constant 7% discount rate, consistent with standard agricultural investment assessment practices, and assumes that annual GM remain constant in real terms over the full investment period. A core component of the calculation is the present-value factor for a 20-year annuity at 7%, which equals 10.594 and is used to convert each system's annual GM into the present value of 20 years of income.

To compute the NPV for each system, the annual GM was multiplied by the present-value factor to yield the present value of 20-year gross margins. These values were then adjusted for system-specific capital expenditure (capex). The capex assumptions were constructed using the NT Farmers' economic impact analysis (2020), which lists $10,000/ha for black-soil land development, $5,000/ha for furrow irrigation and surface-water infrastructure, and $15,000/ha for groundwater development and pivots. This results in total estimated capital costs of $15,000/ha for furrow irrigation, $25,000/ha for overhead/pivot irrigation, and $10,000/ha for rainfed systems.

Subtracting capex from the present value of GM produces the NPV, which indicates the system's profitability over the 20-year horizon after accounting for investment costs. Additional financial indicators were also generated: simple payback period (capex divided by annual GM), discounted payback period (years required for discounted cash flows to recover capex), and the Equivalent Annual Value (EAV), which expresses NPV as a uniform annualised return over 20 years. Break-even GM values were also calculated by solving for the GM at which NPV equals zero (Table 4.2).

Table 4.2. Long-run financial performance of rainfed and irrigated cotton production systems in the Daly River Catchment over a 20-year investment horizon at a 7% discount rate, incorporating system-specific capital expenditure.

System	PV of 20-year GM (AU$/ha)	Capex ($/ha)	NVP ($/ha)	Simple payback (yr)	Discounted payback (yr)	EAV ($/ha/yr)
Furrow irrigation	25,817.61	15,000	10,817.61	6.2	9	1,021
Overhead irrigation (pivot)	25,457.42	25,000	457.42	10.4	20	43
Rainfed (single skip)	8,941.35	10,000	–1,058.65	11.8	>20 (not recovered)	-100

Note: Figures are not directly comparable to the annual gross margins in Table 4.1.

It is important to distinguish between the annual gross margin reported in Table 4.1 and the long-run investment metrics reported in Table 4.2. The GM of AU$844/ha reflects seasonal revenue above variable operating costs only, whereas the EAV of –AU$100/ha/yr incorporates the AU$10,000/ha land-development capital cost and the time value of money discounted at 7% over 20 years, two costs that are invisible to a single-season gross margin calculation but central to investment appraisal.

The NPV results reveal clear differences in the financial performance of the three cotton production systems. Irrigated furrow emerges as the strongest performer, with a 20-year NPV of just over $10,800/ha and an EAV above $1,000/ha/year (Ag Econ, 2025d). Critically, however, these returns are predicated on water being effectively cost-free to the irrigator, a condition that currently holds in the NT but is explicitly flagged for reform under the Territory Water Plan (NTG, 2023). As the NT moves toward volumetric water pricing, the cost advantage underpinning furrow irrigation's strong NPV will erode materially, given its comparatively high-water demand of 8.9 ML/ha (Ag Econ, 2025d). Sensitivity analysis presented in this report demonstrates that a water price increase of just AUD $100/ML reduces the present value of furrow irrigation gross margins by over AUD $9,000/ha, sufficient to eliminate most of the system's NPV advantage.

This dependence on zero-cost water represents the single greatest structural vulnerability in the furrow irrigation financial case, and any investment decision based on current NPV figures must explicitly account for the near-certain introduction of water charges under forthcoming NT water policy reforms (NTG, 2023; NTG, 2024). The discounted payback period of approximately nine

years, while currently attractive, would lengthen considerably under even modest water-pricing scenarios, warranting caution in treating present NPV estimates as a reliable long-term baseline (Hone et al., 2022).

In contrast, the overhead (pivot) system shows only a slightly positive NPV of around $457/ha, with an EAV of just $43/ha/year. This reflects the significantly higher upfront capital requirement resulting from the need to develop groundwater extraction and purchase pivot equipment, as outlined in the NT Farmers development cost estimates. While its annual GM is strong, the higher capex absorbs nearly the entire present value of expected returns, resulting in a discounted payback period that extends to the full 20-year horizon. This means the system is financially viable under current assumptions, but only marginally so, and is sensitive to small declines in yield or price, as well as to increases in operating costs.

The rainfed single-skip system shows a negative NPV of approximately –$1,059/ha, driven by a comparatively low annual GM of $844/ha, which is insufficient to recover the $10,000/ha land-development cost over the 20-year timeframe. The model indicates no discounted payback within the analysis horizon, and the negative EAV suggests that, under the assumed conditions, rainfed cotton provides a return insufficient to justify the capital investment alone. The break-even GM for rainfed production is approximately $944/ha, meaning that even modest improvements in yield or price could push it into positive territory; alternatively, a lower up-front capex (e.g., staged or partial development) would significantly change the outcome.

This outcome is consistent with agronomic modelling that identifies high rainfall variability, cloud-affected radiation, and short soil-moisture windows as major constraints to stable cotton yields in Northern Australia (Rhebergen and Yeates, 2023). International literature further confirms that rainfed cotton systems are among the most financially vulnerable to climate variability, particularly under warming conditions (Kassa et al., 2026; Shikha et al., 2022).

4.6 Sensitivity analysis

4.6.1 Sensitivity to cotton price

Cotton price volatility is a dominant determinant of profitability because gross margins in both irrigated and rain-fed systems scale almost linearly with lint value. Global studies show that cotton is among the world's most price-sensitive fibre crops, with farm-gate profitability responding sharply to fluctuations in international markets, exchange rates, and synthetic fibre competition (OECD and FAO, 2025; Saini et al., 2023). Price risk is particularly acute in regions such as northern Australia, where yields are highly variable and production costs (e.g., transport, energy) are higher than in major exporting nations (Cotton Australia and CRDC, 2024).

For irrigated production in the DRC, a base yield of 11 bales/ha means that every AUD $50/bale reduction in price decreases annual gross margins by AUD $539/ha, substantially lowering NPV (Ag Econ, 2025f; CottonInfo, 2025). At a price of $558/bale, annual GM falls to $1,358/ha, reducing, but not eliminating, long-term profitability. This aligns with global modelling showing that irrigated cotton retains positive margins under moderate price shocks due to its higher yield stability (Jans et al., 2021).

Rainfed cotton is significantly more exposed to price shocks. With yields around 4 bales/ha, a drop to $279/bale renders the system unviable, as gross margins fall below zero (Ag Econ, 2025g; CottonInfo, 2025). This sensitivity is consistent with climate–economic analyses demonstrating that rainfed cotton in tropical environments is double-exposed to both market and climate volatility, making profitability highly unstable (Kassa et al., 2026; Shikha et al., 2022).

4.6.2 Sensitivity to water cost

Irrigation costs account for a major share of variable expenses in northern cotton systems. As the NT moves toward volumetric water pricing under the Territory Water Plan (NTG, 2023; NTG, 2024), future water charges, particularly those above AUD $50–$100/ML, will materially influence gross margins.

Table 4.3 shows how much the PV falls if the $/ML rises by AUD 50/ML or AUD 100/ML relative to the budget assumptions, using the same 20-year, 7% discount rate. This differential reflects the significantly lower sourced water requirement of overhead irrigation (6.7 ML/ha vs 8.9 ML/ha). Similar findings are reported in irrigation-efficiency studies across northern Australia and arid regions globally, where centre pivots consistently deliver stronger $/ML outcomes and improve resilience to higher water prices (McLeod et al., 2024; Zhang et al., 2025).

Energy-efficient pumping systems (solar-diesel hybrids, variable speed drives, and optimised pumping windows) further magnify the water-cost advantage of overhead systems by lowering the electricity/energy cost per ML, which has been shown to improve long-term profitability in both Australian and U.S. irrigation case studies (Ag Econ, 2025f; CottonInfo, 2025; Koudahe et al., 2021).

Rainfed cotton system remains unaffected by water pricing, providing a potential "policy hedge" for growers under future water-market reforms.

Table 4.3. Sensitivity of the present value of 20-year operating gross margins per hectare to volumetric water pricing increases of AU$50/ML and AU$100/ML above baseline assumptions, at a 7% discount rate.

Δ Water price (AU$/ML)	Furrow PV (AUD/ha)	Overhead PV (AUD/ha)
+0 (baseline)	25,817.61	25,457.42
+$50/ML	21,262.19	22,544.06
+$100/ML	16,706.76	19,630.71

Note: Capital expenditure is excluded. Figures reflect gross margin decline only and should be read alongside the full NPV results in Table 4.2

4.6.3 Sensitivity to discount rate

The discount rate reflects the investor’s cost of capital, inflation expectations, and risk appetite. Large capital-intensive agricultural systems, such as irrigated cotton, are highly sensitive to discount-rate changes because cash flows occur over long horizons and are front-loaded with capital expenditure (Gittinger, 1985; Hone et al., 2022).

The discount-rate sensitivity analysis was designed to test how the long-term financial performance of three cotton production systems, irrigated furrow, irrigated overhead (pivot), and rainfed, changes when the assumed discount rate varies between 3% and 12%. For each discount rate, the analysis recalculates the present value of 20 years of annual GM by applying the standard annuity present-value factor.

This factor declines as the discount rate increases, meaning that future income is valued less heavily under higher rates. To compute each system’s NPV, the present value of the 20-year GM is reduced by the system-specific capital investment. These capital costs incorporate black-soil land development and the additional infrastructure appropriate to each system, such as surface dams and furrow irrigation structures or groundwater development and pivot systems, as outlined in the NT Farmers economic impact analysis (2020).

The model also calculates discounted payback periods by summing discounted annual returns until they equal or exceed the initial capital cost. This metric provides an intuitive sense of

investment timing: higher discount rates slow the accumulation of discounted cash flows, lengthening or eliminating payback. Finally, the analysis computes EAV, which converts each NPV into a uniform annualised return, allowing easier comparison across discount rates.

By repeating this process for discount rates of 3%, 5%, 7%, 9%, 10%, and 12%, the results reveal how sensitive each system is to the cost of capital and how robust its profitability is under varying financial conditions.

Table 4.4 demonstrates a clear hierarchy of robustness among the three cotton systems. Irrigated furrow is consistently the strongest performer across the full range of discount rates. At the lowest discount rate (3%), furrow irrigation produces an NPV exceeding $21,000/ha, reflecting the relatively high gross margins and moderate capital costs associated with this system. Even as the discount rate rises to 12%, furrow irrigation continues to deliver a positive NPV of roughly $3,200/ha, indicating a resilient investment profile. The discounted payback period increases gradually from 7 years at 3% to 12 years at 12%, but remains well within the 20-year analysis window.

Table 4.4. Sensitivity of 20-year Net Present Value per hectare to discount rates ranging from 3% to 12% for rainfed and irrigated cotton production systems in the Daly River Catchment, incorporating system-specific capital expenditure. Values rounded to the nearest $10.

Discount rate	Furrow irrigation ($/ha)	Overhead irrigation (pivot) ($/ha)	Rainfed (single skip) ($/ha)
3%	21,260	10,750	2,560
5%	15,370	4,950	520
7%	10,820	460	-1,060
9%	7,250	-3,060	-2,300
10%	5,750	-4,540	-2,820
12%	3,200	-7,050	-3,700

Note: Results should be read alongside Figure 4.1, which illustrates the rate at which each system's NPV crosses zero as the cost of capital increases. Further detail provided in Section 8.2.

The overhead (pivot) system, by contrast, shows substantial sensitivity to discount rate because of its significantly higher capital requirement. At low discount rates (3–5%), pivot irrigation is financially attractive, with NPVs ranging from $4,900/ha to $10,700/ha. However, at the standard 7% rate, the NPV shrinks to a marginal $457/ha, and discounted payback extends to the full 20-year horizon. Once the discount rate exceeds approximately 7%, pivot irrigation becomes uneconomic, generating negative NPVs of –$3,064/ha, –$4,542/ha, and –$7,051/ha at 9%, 10%, and 12%, respectively. This rapid decline highlights the vulnerability of high-capex systems to the cost of capital.

The rainfed system exhibits the lowest resilience to changes in the discount rate. Its comparatively modest annual GM cannot recover even the lower land-development cost at a discount rate of 7% or higher. Although rainfed cotton generates a positive NPV at the lowest discount rates tested (e.g., $2,557/ha at 3%), it quickly turns negative, falling to –$1,059/ha at 7% and worsening as the rate rises. Discounted payback is achieved only at the lowest rates tested (3% and 5%), and even then requires 15–19 years. Because rainfed production lacks the yield-driven GM strength of irrigated systems, its financial viability is highly dependent on both low discount rates and minimised land-development capital expenditure.

Figure 4.1 provides an intuitive visual representation of how each system's profitability declines as the cost of capital increases. The furrow irrigation curve begins at a high NPV level and slopes gradually downward, crossing zero only near the 15% mark. This gentle decline reflects the combination of strong gross margins and moderate capital costs; even under relatively expensive financing conditions, the system continues to generate returns that exceed investment outlays.

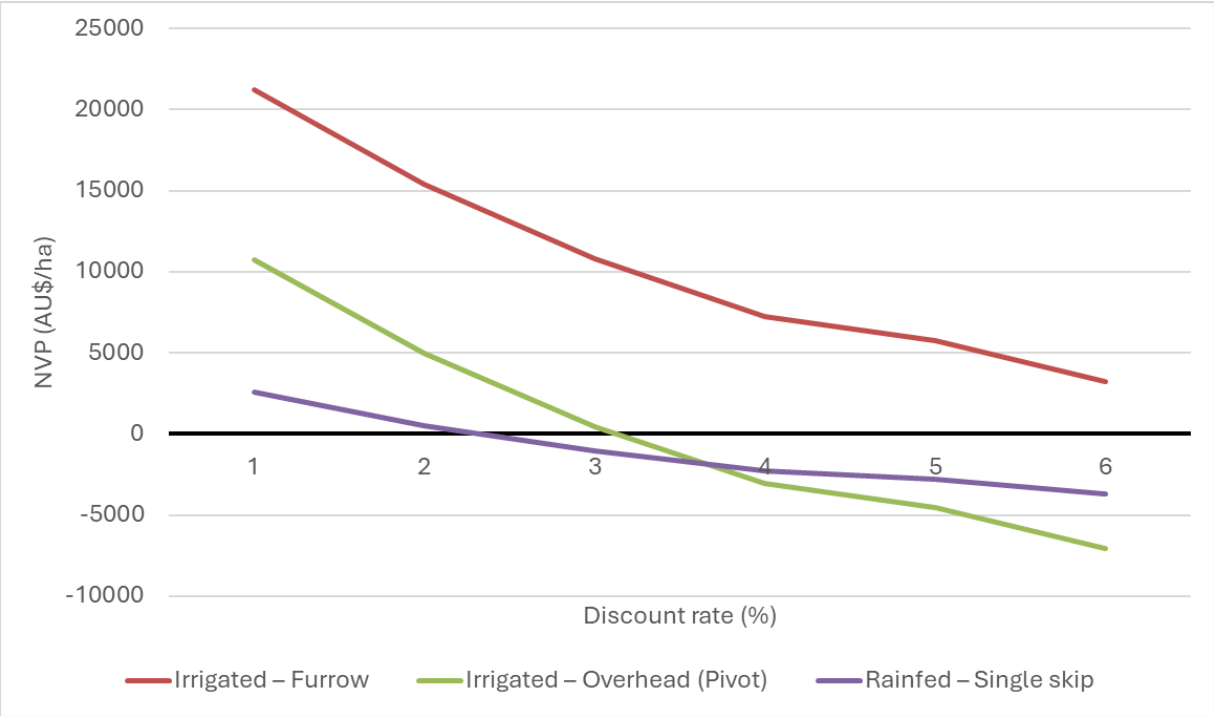


Figure 4.1. Net Present Value per hectare of rainfed and irrigated cotton production systems in the Daly River Catchment across discount rates of 3–12%, incorporating system-specific capital expenditure. The intersection of each curve with the zero-NPV line indicates the maximum discount rate at which each system remains financially viable.

In contrast, the overhead irrigation curve is steep. It intersects the zero line very close to the 7% mark, confirming that even modest increases in the discount rate above typical agricultural benchmarks can render the system unprofitable. This steepness visually highlights the disproportionate influence of high capital expenditure on investment feasibility: small decreases in the present value of future GM translate into rapid erosion of NPV, consistent with broader investment analyses showing that high-capex irrigation is disproportionately affected by higher discount rates (CRCNA, Ag Econ, 2025f; 2020).

The rainfed curve begins much closer to zero and crosses into negative territory between 5% and 6%. Its steeper slope indicates that the system's low gross margins cannot sustain profitability once future cash flows are more heavily discounted. Beyond 7%, rainfed cotton remains solidly negative, and the system shows no recovery even at the upper end of the 3–12% range. The visual thus reinforces the idea that rainfed cotton, while lower in capex, does not produce sufficient GM to offset the time value of money unless discount rates are very favourable.

4.7 Risks of cotton production

The feasibility of cotton production in the DRC is shaped by a combination of agronomic, economic, climatic, and social factors. While recent trials and industry expansion indicate potential

for cotton in Northern Australia, the region's unique wet–dry tropical environment introduces significant risks that must be carefully assessed.

4.7.1 Climate risks

Cotton in the DCR is highly sensitive to seasonal variability. Rain-fed systems rely on reliable wet-season rainfall; however, historical climate analyses reveal high variability in onset and intensity, influenced by the phases of the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Madden-Julian Oscillation (MJO) (CRCNA, 2020; CottonInfo, 2025).

Cloudiness during the flowering period reduces incoming solar radiation, and extended periods below critical thresholds (<24 MJ m^{-2} day^{-1}) can result in boll shedding and reduced lint yield. These dynamics are well documented in northern production manuals and are exacerbated in wet season environments where sustained convective cloud cover suppresses radiation during critical reproductive stages (CottonInfo, 2025).

Temperature-related stresses further compound production risk. Hot nights (≥24 °C) elevate dark respiration, reduce pollen viability, and increase fruit shedding, effects that become more severe when combined with high daytime temperatures (CRCNA, 2025). Experimental studies demonstrate that elevated night-time temperatures significantly shorten the boll maturation period, reduce lint percentage, and suppress seed weight, with high day/night temperature combinations (36/28 °C) causing reductions of up to 86% in seed weight per plant relative to optimal conditions (Thenveettil et al., 2025).

These findings align with broader evidence showing that cotton's reproductive development is highly vulnerable to heat extremes. Reviews of global cotton physiology highlight that heatwaves and warm nights can sharply reduce boll retention and fibre quality, with heat stress during flowering and early boll fill representing the most yield-sensitive period (Saini et al., 2023). Research from Arkansas and the U.S. Cotton Belt similarly shows that elevated night temperatures reduce boll growth rates, increase respiration, and contribute to year-to-year yield variability (Arevalo et al., 2003).

Excessive rainfall during boll opening increases the likelihood of boll rot, staining, and fibre downgrades, risks already identified in climate analyses of northern Australia (CRCNA, 2025). Furthermore, global modelling studies predict continued shortening of cotton's phenological phases as temperatures rise, increasing sensitivity to rainfall timing and temperature during key growth windows (Arshad et al., 2021).

While irrigated systems can mitigate water-deficit stress and buffer against late-season rainfall failure through controlled water supply, they remain susceptible to heat-induced fruiting losses. However, irrigated cotton can employ compensatory growth to recover boll load if favourable conditions return, whereas rain-fed cotton typically "cuts out" early once the soil profile dries (Ag Econ, 2025b).

Finally, climate change projections indicate that rising temperatures, more frequent extreme weather events, and shifts in rainfall distribution will disproportionately affect rain-fed systems globally (Kassa et al., 2026). International reviews warn that even modest increases in mean temperature (>1 °C) can depress cotton yields and degrade fibre quality, with rain-fed systems facing the highest exposure due to their dependency on increasingly erratic rainfall (ICAC, 2020).

Together, these climate-driven stresses: cloudiness, rainfall variability, heat extremes, and high night-time temperatures, position cotton in the DRC as a climate-sensitive crop requiring careful risk management, particularly for rain-fed systems.

4.7.2 Pest and disease risks

Pest and disease pressures further complicate cotton production in the DRC. Boll rot, *Verticillium wilt*, and established biosecurity threats such as fall armyworm (*Spodoptera frugiperda*) continue to increase management risk in northern Australia (Ag Econ, 2025b; CRDC and CottonInfo, 2025b). A further and regionally specific emerging threat is the bicoloured weevil, a native Australian insect distinct from the exotic boll weevil (*Anthonomus grandis*) of the Americas, which was first recorded feeding on pollen in commercial cotton flowers in the Douglas Daly region in 2021 and has since increased in population with each successive season (Brann, 2026). The primary yield-damage mechanism is larval: females lay eggs directly into developing bolls, and larval development within the boll causes the plant to shed it, resulting in a direct loss of harvestable lint (Brann, 2026). While bicoloured weevils have been detected in cotton crops in Queensland and the Ord Irrigation Scheme in Western Australia, population densities in the NT are substantially higher than in any other production region (Brann, 2026). Critically, no pesticides are currently registered specifically for bicoloured weevil control in cotton, leaving growers reliant on incidental suppression during routine integrated pest management sprays and on inter-seasonal field hygiene to prevent ratoon cotton from acting as a population reservoir between crops (Brann, 2026).

The NT Department of Agriculture and Fisheries is actively investigating future control options, and the industry's current position, characterised by Cotton Australia as alert but not alarmed, reflects the absence of a dedicated management tool and the pest's still-expanding geographic and seasonal footprint (Brann, 2026).

Recent global literature shows that *Verticillium wilt* remains one of the most economically damaging diseases in cotton worldwide, capable of causing up to 80% yield loss in severe infections, with more than 400 host plant species acting as pathogen reservoirs (Le et al., 2026). Early expression commonly includes interveinal yellowing, vascular discolouration, and unilateral plant wilt, with severity influenced by soil inoculum levels, soil texture, and temperature regimes. In response, modern management emphasises integrated approaches combining resistant cultivars, crop rotations with non-host species, soil solarisation, and improved diagnostics, such as Raman spectroscopy-based early-detection tools, achieving up to 97.5% classification accuracy, enabling earlier intervention and reduced yield losses (Wang et al., 2025). The convergence of established pathogens, endemic insect pressures, and the emerging bicoloured weevil threat underscores that pest and disease risk in the DRC is both multi-dimensional and escalating, warranting explicit inclusion in any long-term economic assessment of cotton viability in the region.

4.7.3 Production and agronomic risks

Rain-fed cotton in the DRC faces significant establishment challenges due to poor trafficability during the early wet season. Heavy rainfall events limit machinery access, and sowing windows are narrow; thus, rain-fed cotton is typically established in December to maximise the utilisation of early monsoonal rainfall. In contrast, irrigated cotton systems have greater planting flexibility, with an optimal window from mid-January to mid-March, aligning flowering with the seasonal decline in cloud cover, a critical factor for maximising solar radiation during reproductive development.

(CottonInfo, 2025).

Irrigated systems require precise scheduling and water management to avoid waterlogging, particularly on heavier soils, and to mitigate heat stress during peak summer conditions. Waterlogging reduces root function and increases susceptibility to disease, while poorly timed irrigation can interact with high temperatures to exacerbate boll loss (Rhebergen and Yeates, 2023). Cotton production manuals consistently emphasise that irrigated cotton must be managed with attention to timing, soil moisture profiling, and heat-avoidance strategies (CRDC and CottonInfo, 2025a).

Top-end soils present significant structural limitations and are characterised by extreme spatial variability; within a single 100-hectare patch, two to three distinct soil types may co-occur, creating highly heterogeneous production conditions that complicate uniform crop management (CRCNA, 2020). Many soils in the DRC have low plant-available water capacity (PAWC), often holding only 80–125 mm of usable moisture, meaning rainfed cotton can experience water stress within 8–10 days of rainfall cessation, particularly during high evaporative-demand periods (CRCNA, 2020). Where heavier clay soils are present within this mosaic, waterlogging risk is a critical additional constraint: these soils have low hydraulic conductivity and poor internal drainage, and sustained monsoonal rainfall events can rapidly saturate the profile, reducing root function, increasing susceptibility to root-zone disease, and causing direct yield loss through oxygen deprivation during sensitive growth stages (Rhebergen and Yeates, 2023). Low PAWC soils magnify the risk of rainfall distribution, regardless of soil texture: even in years with normal total rainfall, poor spacing of rainfall events can lead to prolonged stress periods, limiting boll retention and reducing final yields (CRCNA, 2020). Together, this soil patchiness and the juxtaposition of droughty low-PAWC profiles with waterlogging-prone heavy soils within the same paddock represent one of the most operationally challenging aspects of cotton production in the DRC, requiring detailed soil mapping prior to any investment decision.

4.7.4 Economic and infrastructure risks

Irrigated cotton yields (≈10–12 bales/ha) are higher than rainfed systems (≈4–5 bales/ha), but they require substantial capital investment in irrigation infrastructure. Irrigation development requires major upfront capital expenditure, including pumps, pivots or furrow systems, electricity or diesel infrastructure, and water-storage capacity. These costs must be amortised over a 20-year horizon to account for equipment replacement cycles. Ongoing water charges further elevate operating costs, increasing financial exposure to changes in energy prices, water pricing, and regulatory conditions (Ag Econ, 2025c, 2025d, 2025f, 2025h).

Beyond water-related costs, the reliability and efficiency of freight, ginning, and supply-chain logistics remain critical constraints. Although the establishment of the Katherine gin has substantially reduced transport distances for NT growers, northern cotton supply chains remain vulnerable to fuel-price volatility and periodic disruptions to transport networks (CRCNA, 2020). Broader agricultural supply-chain analyses show that bottlenecks in freight, port congestion, and labour shortages have increased input and logistics costs by 15–25% in recent seasons, contributing to delayed delivery of fertiliser, machinery parts, and other critical inputs, delays that can directly lower yields or reduce fibre quality. Global trends in cotton supply chains also suggest continued exposure to geopolitical risks, including tariff fluctuations and trade disruptions, which influence shipping costs and downstream order volumes (Salfino, 2025).

Processing capacity, while improving, remains another infrastructure-linked risk. Delays in ginning can reduce fibre quality, especially during peak harvest periods when humidity is high. Labour shortages in transport or ginning services can further constrain throughput capacity. Supply chains with limited redundancy, such as reliance on a single regional gin, face heightened risk if operational issues occur (Cotton Gins Association, 2025).

Rain-fed systems, although less capital-intensive, deliver lower and more variable gross margins, making profitability highly dependent on seasonal conditions (Ag Econ, 2025e, 2025g). These systems are particularly exposed to climatic shocks such as late wet-season onset, prolonged dry spells, or cloud-affected flowering, all of which drive significant year-to-year income variability. Rising global production costs, such as fertiliser, fuel, and insurance, further squeeze profitability for rain-fed operations, particularly when yields fall below expectations. Broader economic analyses indicate that cotton producers worldwide face rising production costs, heightened

competition from synthetic fibres, and downstream supply-chain uncertainty, all of which are tightening margins for lower-input systems (OECD and FAO, 2025).

4.7.5 Policy and social licence risks

Water governance remains the most significant constraint on the expansion of cotton production in the DRC. Groundwater supplies approximately 80% of consumptive water use in the region, and key aquifers, most notably the Oolloo Dolostone, are already fully allocated, with some management zones assessed as over-allocated. These conditions limit the availability of new entitlements and heighten scrutiny over any additional extraction (NTG, 2019).

The NT water policy emphasises sustainable allocation and compliance under “use it or lose it” frameworks, placing pressure on irrigators to demonstrate water-use efficiency. These frameworks require irrigators to demonstrate active and efficient use of their entitlements, with failure to do so potentially triggering recovery of unused licence volumes. The Territory Water Plan (2023) reinforces this direction, outlining reforms focused on water security, governance improvements, transparent compliance, and stronger engagement with Traditional Owners in water management decision-making. (NTG, 2023).

Despite these policy signals, national and regional reviews highlight persistent weaknesses in NT water governance. Academic analysis describes the NT as a “hydrological frontier”, a jurisdiction where water law and planning frameworks continue to institutionalise inequities, particularly around Indigenous access, recognition of cultural water values, and procedural fairness in licensing (O’Donnell et al., 2022). Benchmarking against the National Water Initiative shows the NT lags behind national standards, with regulatory gaps exposing Traditional Owners to insecure rights and insufficient involvement in water allocation processes.

Social licence considerations, including Indigenous engagement and protection of cultural heritage, are crucial for project approval and long-term viability. Failure to address these factors can result in reputational risk and regulatory delays (CRCNA, 2020).

4.8 Feasibility assessment

The Feasibility Matrix (Figure 4.2) compares rainfed and irrigated cotton systems across seven critical factors: economic viability, climate risk, water security, capital investment, compliance complexity, social licence and pest and disease risk. The matrix was constructed by the authors using a Multi-Criteria Evaluation (MCE) framework, a widely applied approach in agricultural systems assessment for structuring complex decisions involving environmental, social, and economic trade-offs (Minh, 2024).

Each factor was scored on a scale from 1 (low) to 3 (high) by the authors based on a synthesis of published industry benchmarks, regional agronomic data, and water policy documentation, following descriptive MCE practice for qualitative comparisons in early-stage feasibility analysis (Minh, 2024). It should be acknowledged that author-assigned scoring introduces subjectivity, and the scores should be interpreted as informed qualitative rankings rather than precise quantitative measures.

Feasibility criterion	Rainfed system	Irrigated system	Source basis
	Score: 1 = Low | 2 = Medium | 3 = High		
Economic viability	**Low (1)**	**High (3)**	*Ag Econ (2025d, 2025f, 2025g); Kassa et al. (2026)*
Climate risk	**High (3)**	**Medium (2)**	*CRCNA (2025); Shikha et al. (2022); Jans et al. (2021)*
Water security	**High (3)**	**Low (1)**	*NTG (2019, 2023); Cotton Australia & CRDC (2024)*
Capital investment	**Low (1)**	**High (3)**	*NT Farmers Association (2020)*
Compliance complexity	**Low (1)**	**High (3)**	*NTG (2023); Dept of Lands Planning & Environment (2023)*
Social licence	**Medium (2)**	**Medium (2)**	*Control Union (2024); McLeod et al. (2024)*
Pest & disease risk	**High (3)**	**Medium (2)**	*Ag Econ (2025b); CRDC & CottonInfo (2025b); Le et al. (2026); Dept Agriculture & Fisheries (2025)*

Figure 4.2. Feasibility matrix chart comparing rainfed and irrigated cotton systems for the Daly River Catchment

The differential scores for capital investment and compliance complexity directly reflect documented cost and regulatory burdens. Irrigated systems score 3 because they require major upfront capital expenditure, including pumps, pivots or furrow infrastructure, and groundwater development, estimated at AUD $15,000–$25,000/ha (NT Farmers Association, 2020), alongside ongoing obligations for metering, reporting, and water-use efficiency compliance under NT licensing frameworks (NTG, 2023; DLPE, 2023). Rainfed systems score 1 because they require no water extraction licence, carry minimal infrastructure costs, and face no volumetric reporting obligations (NTG, 2019). These contrasting regulatory and capital profiles are well-documented in the broader irrigated agriculture literature and are not unique to the NT context (Zhang et al., 2025).

Irrigated cotton scored highest for economic viability owing to its consistently strong yields, typically 10–12 bales per hectare, and gross margins approaching AUD 2,400 per hectare (Ag Econ, 2025d, 2025f). Rainfed cotton, by contrast, shows marginal profitability, with yields heavily constrained by rainfall variability (Ag Econ, 2025g). These findings are consistent with broader studies showing that irrigated production generally maintains more stable yields under climate variability, while rainfed production remains substantially more sensitive to seasonal conditions (Jans et al., 2021; Shikha et al., 2022). In the context of the DRC, where climate variability is strongly influenced by ENSO and IOD cycles, a reliable irrigation water supply provides a clear economic advantage.

Rainfed cotton was assessed as high climate risk due to its dependency on monsoonal rainfall, which is highly variable in timing and intensity. Rainfall deficits, especially during critical growth periods such as flowering, can sharply reduce yields (CRCNA, 2025). This aligns with climate modelling studies showing that rainfed cotton systems exhibit significantly greater sensitivity to projected changes in rainfall patterns and temperature extremes (Shikha et al., 2022). Irrigated cotton receives a moderate climate-risk score because controlled water availability buffers against seasonal variability; however, it remains vulnerable to extreme heat events and long-term climate trends. Under future climate scenarios, irrigated cotton is projected to experience fewer yield losses than rainfed systems, particularly when CO_2 fertilisation benefits are included (Jans et al., 2021).

Water security strongly favours rainfed systems, which avoid dependence on formal water entitlements. Irrigated cotton requires consistent allocations, and in the NT, growers are subject to stringent water-licensing frameworks and "use it or lose it" provisions, increasing operational risk (NTG, 2019, 2023). These findings reflect broader national insights: irrigated cotton is water-

efficient but heavily dependent on secure licences and regulated extraction (Cotton Australia and CRDC, 2024; McLeod et al., 2024). Rainfed systems bypass these constraints by relying on natural rainfall, though their reliability is inherently tied to climatic variability.

Pest and disease risk was scored High (3) for rainfed systems and Medium (2) for irrigated systems. Rainfed cotton in the DRC faces compounded pest and disease exposure: wet-season trafficability constraints limit timely pesticide application, sustained monsoonal rainfall promotes boll rot and fungal disease, and fall armyworm (Spodoptera frugiperda) is now classified as an endemic pest across the NT with no feasible eradication pathway (Department of Agriculture and Fisheries, 2025; CRDC and CottonInfo, 2025b). Verticillium wilt presents a further systemic risk, capable of causing yield losses of up to 80% under severe infection, with soil inoculum levels and temperature regimes in the DRC creating conducive conditions (Le et al., 2026). Irrigated systems receive a moderate score because improved field access, scheduled management windows, integrated pest management strategies, and the availability of Bt cotton varieties provide meaningful risk mitigation (Ag Econ, 2025b; CRDC and CottonInfo, 2025b). However, dense irrigated canopies can elevate disease pressure, and fall armyworm remains a system-wide threat regardless of irrigation method, meaning neither system is fully insulated from pest-related yield loss.

Both systems received medium scores for social licence. Stakeholder expectations regarding sustainability, water stewardship, and engagement with Indigenous communities apply equally to rainfed and irrigated production in the DRC (CRCNA, 2020). Social licence considerations are increasingly influenced by consumer preferences for ethically and sustainably produced fibres, with rainfed systems often perceived as more environmentally aligned due to lower water extraction demands (Control Union, 2024). At the industry level, demonstrable improvements in water-use efficiency, such as those documented in long-term Australian benchmarking studies, also enhance public trust in irrigated systems (McLeod et al., 2024).

When synthesised across all seven criteria, the matrix indicates that irrigated cotton remains the most economically attractive option in the DRC, despite its higher capital, regulatory, and disease-management requirements. Its consistent yields and stronger gross margins, reflected in a 20-year NPV exceeding $10,800/ha for furrow irrigation, outweigh the disadvantages related to water security and compliance (Ag Econ, 2025d). However, it is critical to note that these NPV figures assume water is currently available at no direct cost to the irrigator, a condition explicitly targeted for reform under the Territory Water Plan (NTG, 2023). The introduction of volumetric water pricing would materially erode the financial advantage of irrigated systems, particularly furrow irrigation, which has a higher water demand of 8.9 ML/ha, and must be treated as a near-certain future cost in any investment planning (Ag Econ, 2025d; NTG, 2023). Within irrigated technologies, overhead irrigation demonstrates superior performance, producing approximately 1.87 bales per megalitre compared with 1.28 bales per megalitre under furrow systems, and its lower water demand of 5.5–6.7 ML/ha positions it more favourably under future water-pricing scenarios (Cotton Australia and CRDC, 2024; McLeod et al., 2024).

Rainfed cotton, while less profitable, offers a low-risk, low-cost entry point for diversification strategies or transitional development. However, its long-term viability is constrained by high climate exposure, elevated pest and disease risk, and variable yields (Kassa et al., 2026; Shikha et al., 2022). Strategic investment in irrigation infrastructure, supported by efficient energy systems, robust water-planning frameworks, integrated pest management, and strong community partnerships, offers a more reliable pathway for sustained cotton development in the DRC.

4.9 Farm scale economics

4.9.1 Minimum variable farm size

The minimum viable farm size for cotton in northern Australia is largely determined by the economics of ginning and freight. Industry analyses and CRCNA reports indicate that a regional gin requires ~55,000–75,000 bales annually for commercial viability, translating to around 7,500 hectares of irrigated cotton at 9 bales/ha or a mix of irrigated and rain-fed systems (CRCNA, 2020).

At the individual farm level, 500–1,500 ha of irrigated cotton is often cited as the threshold for achieving economies of scale in machinery use, irrigation infrastructure amortisation, and contract efficiencies. Smaller farms (<500 ha) face higher per-unit costs for equipment and logistics unless integrated into cooperative models or supported by custom contracting (NT Farmers Association, 2020).

4.9.2 Economies of scale analysis

Economies of scale are vital in the north due to the high costs of specialised equipment and the "tyranny of distance" affecting logistics (CRCNA, 2020; NT Farmers Association, 2020).

Development costs for greenfield sites are high, with a "rule of thumb" cost of $10,000 per hectare (NT Farmers Association, 2020). This creates significant barriers to entry that only large-scale operations or "at-scale" agricultural precincts can mitigate through cost-sharing and reduced transportation expenses (NT Farmers Association, 2020).

Essential machinery, such as cotton pickers, costs approximately $1.25 million per unit. Larger farms can justify these purchases, whereas smaller operations must rely on contractors, who may be difficult to attract without a regional critical mass of growers (CRCNA, 2020).

Proximity to a gin or processing plant is a major economic driver. The establishment of a cotton gin in Katherine has substantially reduced transport distances for NT growers, significantly improving gross margins relative to the previous situation where raw cotton was freighted thousands of kilometres to Queensland for processing (NT Farmers Association, 2019, 2020; CRCNA, 2020). Nonetheless, northern cotton supply chains remain vulnerable to fuel price volatility and periodic disruptions to transport networks, thereby continuing to pose a material risk to farm-level profitability (CRCNA, 2020).

4.9.3 Optimal enterprise mix and diversification

Research indicates that a single-commodity broadacre model in northern Australia is often marginal. The most value is realised when cropping is integrated into a broader business value proposition (CRCNA, 2020).

Integration with Cattle: The primary recommendation for the region is to integrate broadacre cropping with beef production. This allows the use of high-value by-products, such as cottonseed, as a protein and fat supplement for cattle, reducing the need to pay high freight costs (up to $200/t) for southern feed (CRCNA, 2020).

Diversified rotations are broadly recommended for northern Australian farming systems, with an optimal enterprise mix likely requiring two crops per year or a combination of irrigated and dryland production (CRCNA, 2020). Irrigated systems in the DRC have trialled enterprise combinations including melons, hay, and cotton, though the commercial viability of individual crops under DRC-specific conditions remains uncertain and context-dependent (CRCNA, 2020). Rotational benefits can be achieved by including grain legumes to fix nitrogen and improve soil health, with evidence from broader northern Australian systems suggesting this can improve yields of subsequent primary crops (Adhikari et al., 2025; CRCNA, 2020). Dual-purpose crops such as peanut or

sorghum varieties, harvested for both grain and high-quality hay, represent a further diversification option, though enterprise selection should be guided by site-specific agronomic assessments and verified gross margin data rather than generalised crop lists (NT Farmers Association, 2020; Adhikari et al., 2023).

Risk Mitigation: Diversification into plant-based industries reduces the sector's reliance on beef cattle, which currently represents over 50% of the region's farms, thereby enhancing resilience to market shifts or trade changes (NT Farmers Association, 2020).

4.10 Water efficiency

4.10.1 Gross Production Water Use Index

Based on the 2025-26 gross margin budgets and cotton industry benchmarks, the GPWUI serves as the primary metric for comparing water productivity across different regions and cotton production systems (Pendergast et al., 2019).

The yield and water input figures in Table 4.5 are drawn from the 2025-26 industry gross margin budgets published by Ag Econ through CottonInfo. Specifically, the overhead (pivot) yield of 10.30 bales/ha and water input of 6.70 ML/ha are sourced from Ag Econ (2025f), the furrow (Ord River) yield of 11.00 bales/ha and water input of 8.90 ML/ha from Ag Econ (2025d), and the rainfed single-skip yield of 4.00 bales/ha from Ag Econ (2025e). The rainfed ETc range of 6.5–7.7 ML/ha is sourced from CottonInfo (2025).

Table 4.5. Comparative Gross Production Water Use Index (GPWUI) estimates for rainfed and irrigated cotton production systems in the Daly River Catchment, expressed as lint bales produced per megalitre of water input

Production system	Assume yield (bales/ha)	Estimated water input (ML/ha)	Estimated GPWUI (bales/ML)
Irrigated cotton: Overhead (pivot)	10.30	6.70 (source)	1.54
Irrigated cotton: Furrow (Ord River)	11.00	8.90 (source)	1.24
Rainfed cotton: (Single skip)	4.00	7.10 (Etc mid; 6.5-7.7 range)	0.56 (≈ 0.52–0.62)

Notes: Yield and sourced water figures for irrigated systems are drawn from 2025-26 industry gross margin budgets (Ag Econ, 2025d, 2025f). Rainfed yield reflects northern Australia rain grown benchmarks (Ag Econ, 2025e), and the ETc range of 6.5–7.7 ML/ha is derived from regional crop water requirement estimates (CottonInfo, 2025). The irrigated "sourced" denominator includes conveyance losses but excludes effective rainfall and soil water used; the true total-water GPWUI would therefore be lower than shown.

Overhead irrigation remains the most water-productive option, returning approximately 1.54 bales/ML on a sourced-water basis, combining yields of ~10.3 bales/ha with comparatively lower water volumes than those delivered by typical surface systems (Ag Econ, 2025f). On an applied-water basis, this advantage is even more pronounced, with overhead irrigation achieving ~1.87 bales/ML at 5.5 ML/ha applied (Ag Econ, 2025f). This is consistent with industry guidance that, when correctly sized and managed, overhead systems can reduce applied water relative to furrow irrigation, often at the cost of higher energy exposure (CRDC and CottonInfo, 2025a; Ag Econ, 2025f).

Critically, however, all GPWUI estimates presented here are calculated without a water cost component, as NT irrigators currently access water at no direct charge (NTG, 2023). This is a material omission in the current financial picture: once volumetric water pricing is introduced under the Territory Water Plan, the cost per megalitre will directly reduce gross margins, and the higher water demand of furrow systems (8.9 ML/ha versus 5.5–6.7 ML/ha for overhead) will amplify this cost differential, further strengthening the relative economic position of overhead irrigation under future policy conditions (NTG, 2023; Ag Econ, 2025d, 2025f).

The furrow Ord/Northern case delivers respectable lint (~11 bales/ha) but sits at ~1.24 bales/ML because the seasonal water denominator is larger (8.9 ML/ha sourced). Both patterns align with the manual's applied-water benchmarks for irrigated cotton (~5.4–8.9 ML/ha) and with the overhead vs. furrow trade-offs discussed in cotton industry reports (Ag Econ, 2025c).

For rain-fed cotton in the Top End, GPWUI falls well below irrigated systems when the denominator reflects the crop's full ETc rather than just in-crop rainfall. Using the ETc range in your database (6.5–7.7 ML/ha) and the northern rain-fed yields (≈ 3.6–4.0 bales/ha) produces ~0.50–0.60 bales/ML, with a midpoint around 0.56 for the 4.0-bale/ha case. This lower water productivity is consistent with the environmental constraints that typically suppress lint per unit water in the Daly/Katherine–Douglas–Daly setting, namely, high cloudiness during flowering, hot nights (≥ 24 °C), and wet-season trafficability (CRCNA, 2025; CottonInfo, 2025).

These findings align with industry benchmarks. The 2025 Grower Survey reports a national median GPWUI of ~1.26 bales/ML for irrigated cotton (CRDC, 2025). The overhead and southern-style furrow budget point estimates bracket and (for overhead) exceed that median, as expected from budget scenarios with favourable assumptions. At the same time, industry reports stress that seasonal conditions drive efficiency more than the system choice itself: in very wet or very dry seasons, GPWUI typically weakens due to either non-productive rainfall or heat- or cloud-stress curtailing boll retention, again mirroring the constraints noted for the NT (Cotton Australia and CRDC, 2024; CRDC and CottonInfo, 2025a).

On a GPWUI basis, efficient irrigation, particularly overhead on suitable soils, offers the best "cruising speed" for water-limited profitability in the NT, with well-managed furrow a close second where conveyance and on-farm losses are minimised. Rain-fed systems remain agronomically viable in some seasons/locations but exhibit much lower water productivity once total seasonal water is correctly accounted for, and are highly sensitive to rainfall timing near cut-out (Ag Econ, 2025f).

4.11 Policy linkages: cotton production methods under "use-it-or-lose-it" water governance in the Daly River catchment

In the NT, the management of water resources is increasingly governed by the Management of Unused Licensed Water Entitlements Policy, commonly referred to as the "use it or lose it" approach (NTG, 2019). This policy environment creates significant shifts in how cotton production is planned, financed, and managed in the DRC.

For irrigated cotton, "use-it-or-lose-it" settings create both an efficiency imperative and a utilisation obligation. Overhead (pivot/lateral) irrigation achieved higher water productivity (e.g., higher GPWUI in bales/ML) than furrow irrigation because it meets crop ET with less field-applied water, reducing the volumes of sourced water needed to achieve a given yield. In policy terms, this helps growers right-size entitlements and still meet minimum-use expectations without resorting to wasteful application that would undermine environmental flow rules or trigger compliance risk (CRDC and CottonInfo, Ag Econ, 2025f; 2025a). At the same time, tighter metering and reporting, now a priority in the NT compliance program, constrain any temptation to "use" water merely to

avoid recovery, reinforcing the need for efficiency gains to be real and verifiable (Department of Lands Planning and Environment, 2023).

For furrow irrigation, the policy signal cuts two ways. On one hand, furrow systems in the Ord/Kununurra-style example use more sourced water per bale than overhead, which can make it easier to meet a percentage-use test in wet years; on the other hand, higher losses elevate the risk that licence volumes appear oversized when scrutinised over multi-year horizons, exposing part of the paper entitlement to recovery if actual take sits below the 70% threshold. With enforcement priorities now explicitly listing “recovery of unused licensed water entitlements,” and with an active program of site inspections and meter audits, the safest course is to recalibrate entitlements (or trade out of surplus where available) rather than maintain volumes that are seldom used (NTG, 2021; NTG, 2025).

For rain-fed cotton, the picture is different. Purely rain-fed operations may not carry extraction licences; however, many Top End businesses pursue mixed or opportunistic irrigation. In such cases, if a licence is held “just in case” but rarely used, because late-season rain fails or because wet-season access is constrained, non-use over successive years can trigger recovery. Two policy tools mitigate this: (i) the NT’s staged water extraction licence guidelines, which align licensed volumes with real development milestones, and (ii) the 2025 update enabling broader water trading so holders can transfer unused allocations rather than “using” water unproductively to avoid recovery (NTG, 2025). These options reduce perverse incentives and support social licence by prioritising genuine use over symbolic “use” (NTG, 2020).

To ensure consistent water use and avoid recoupment, researchers suggest that irrigated cotton must be part of an integrated enterprise mix (Adhikari et al., 2025; Adhikari et al., 2023). This might include double-cropping (e.g., following cotton with a winter pulse or fodder crop) to maintain a steady water demand and maximise the return on assets managed (GHD Pty Ltd, 2023).

The "use it or lose it" policy forces a transition from speculative land holding to active, data-driven water management. Success in this environment requires cotton growers to meticulously document their water use using tools such as soil moisture probes and satellite-based scheduling (e.g., IrriSAT) to justify their continued access to the region's finite groundwater resources (GHD Pty Ltd, 2023).

4.12 Strategic recommendations

4.12.1 Prioritise investment in high-efficiency irrigation systems and water-secure development pathways

The long-term economic modelling in this study demonstrates that irrigated cotton, particularly systems using overhead (pivot) irrigation, offers the strongest combination of profitability, water productivity, and resilience to future water-pricing reforms in the DRC. Overhead irrigation consistently delivers higher GPWUI values than furrow irrigation (1.54 vs. 1.24 bales/ML), while requiring significantly less sourced water, lowering both operational exposure and future regulatory risk under the Territory’s emerging volumetric pricing framework. At the same time, the 20-year NPV analysis shows that irrigated systems remain financially viable across a wide range of discount rates, whereas rain-fed cotton becomes unprofitable under moderate capital or climate risk scenarios. For these reasons, policymakers and investors should prioritise irrigation development that maximises water-use efficiency, including investment in energy-efficient pumping, soil-moisture monitoring, and modernised metering infrastructure. Such investments not only strengthen financial returns but also reduce vulnerability to compliance risks associated with “use it or lose it” licensing.

4.12.2 Strengthen water governance, compliance systems, and Indigenous water participation

Given that groundwater supplies approximately 80% of consumptive use in the Daly region and that key aquifers, such as the Oolloo Dolostone, are fully allocated, future cotton expansion depends on transparent, enforceable, and socially legitimate water governance (NTG, 2019). The growing emphasis on metering, audits, and recovery of unused entitlements under the Territory Water Plan underscores the need for robust water-use monitoring and adaptive allocation frameworks that prevent over-extraction while maintaining certainty for irrigators (NTG, 2023). At the same time, research identifies the NT as a “hydrological frontier” where Traditional Owners face systemic inequities in water allocation, participation, and cultural water protection (O’Donnell et al., 2022). A strategic recommendation is therefore to embed Indigenous co-governance mechanisms into all water-planning decisions, including participatory licensing processes, transparent assessment criteria, and resourced community engagement structures. Ensuring Traditional Owners have access to water entitlements, either through Aboriginal Water Reserves or negotiated allocation pathways, enhances social licence and aligns cotton development with national water-justice principles. Strengthening governance in this way reduces regulatory delays, mitigates conflict, and supports long-term industry legitimacy.

4.12.3 Promote farm-scale integration, diversification, and climate-risk mitigation strategies

Both climate-risk modelling and agronomic evidence highlight that cotton production in the DRC is highly sensitive to cloudiness, high night-time temperatures, and rainfall variability, with rain-fed systems experiencing the greatest exposure (CRCNA, 2025; Rhebergen and Yeates, 2023). To improve resilience, cotton should be integrated into diversified enterprise models that combine irrigated cropping with livestock production, rotational legumes, and opportunistic wet-season crops (Adhikari et al., 2025). Evidence presented in this report shows that diversified systems reduce economic volatility, improve soil health, and maximise returns on irrigation infrastructure by enabling multiple annual crop cycles or complementary fodder production.

Integration with cattle enterprises is particularly advantageous, as cottonseed provides a high-value feed supplement that offsets regional transport and feed costs (CRCNA, 2020). Climate-risk mitigation should also include scheduling cotton planting to align peak flowering with declining cloud cover, using heat-avoidance irrigation strategies, and adopting cultivars more tolerant to warm nights or episodic water stress (CottonInfo, 2025; Saini et al., 2023). These measures will enhance the reliability of yield outcomes and support long-term financial performance under increasingly variable climatic conditions.

4.13 Conclusion

The results of this study provide a clear, evidence-based answer to the central question of whether cotton production is a viable and sustainable investment in the DRC. The combined economic modelling, water-efficiency assessment, climate and agronomic risk analysis, and policy review converge on a consistent message: cotton can be viable in the DRC, but only under irrigated systems, and only where production aligns with water-planning frameworks, environmental safeguards, and the social-licence expectations that shape development in the NT.

From an economic perspective, irrigated cotton is the only system that generates a positive long-term return over a 20-year horizon. The NPV and EAV results show that furrow-irrigated cotton delivers the highest profitability, with a 20-year NPV of approximately $10,800/ha and an EAV of $1,000/ha/year or more. These outcomes reflect the combination of strong yields and moderate capital requirements. In contrast, overhead (pivot) irrigation, while more water-efficient,

produces only a marginally positive NPV at a 7% discount rate and becomes unprofitable at discount rates above ~7%. Rainfed cotton performs consistently poorly, with negative NPVs under most scenarios and extreme exposure to climate variability, especially cloud-affected radiation and short wet-season moisture windows, which are characteristic of the Top End. On these economic grounds alone, rainfed cotton should not be considered a primary production strategy in the DRC, though it may serve as a supplementary or transitional land-use option.

The sensitivity analysis shows that future water pricing could materially alter the comparative profitability of irrigated cotton systems in the DRC. The PV of gross margins for furrow irrigation declines from AU$25,817.61/ha under the baseline scenario to AU$21,262.19/ha at AU$50/ML and AU$16,706.76/ha at AU$100/ML, while overhead irrigation declines from AU$25,457.42/ha to AU$22,544.06/ha and AU$19,630.71/ha, respectively. This indicates that furrow systems are more vulnerable to higher water costs because of their greater water demand, whereas overhead irrigation is likely to be more resilient under future policy settings that introduce volumetric water pricing.

When environmental considerations are incorporated, the evaluation shifts further in favour of high-efficiency irrigated systems. Overhead irrigation demonstrates superior water productivity, achieving GPWUI values of 1.54 bales/ML compared with 1.24 bales/ML for furrow systems. This higher water-use efficiency will become increasingly important as the NT advances water-pricing reforms and strengthens compliance under the “use it or lose it” framework. Efficient irrigation reduces sourced-water demand and provides growers with greater certainty that they can meet minimum-use thresholds without compromising environmental flows. Furrow irrigation, while economically stronger, is more water-intensive and therefore more exposed to future water-policy tightening. Nonetheless, both irrigated systems significantly outperform rainfed cotton in terms of water productivity, yield stability, and overall resilience.

The social and governance dimensions of the catchment reinforce the need for a cautious, well-planned approach. The DRC is regarded as a hydrologically sensitive system with strong cultural significance and high ecological value, particularly due to its groundwater-fed dry-season flows. Water governance in the NT remains under scrutiny, with national assessments identifying weaknesses in Indigenous water rights, planning transparency, and compliance enforcement. Any future cotton expansion must therefore align with rigorous metering, transparent reporting, and genuine engagement with Traditional Owners. Irrigated cotton, when tightly integrated with water-allocation plans, documented efficiency measures, and local community priorities, has a greater prospect of maintaining social licence than broad scale, rainfed expansion, which offers neither economic robustness nor environmental justification.

These findings support the conclusion that cotton production is worth pursuing in the DRC only under irrigated systems, and only where development is aligned with land-capability mapping, water-planning constraints, sustainable-yield limits, and community expectations for environmental protection and cultural respect. Of the systems evaluated, furrow irrigation currently provides the strongest financial performance, while overhead irrigation provides the strongest water-use efficiency and long-term alignment with future policy conditions. In practice, the best system for the DRC is likely a hybrid pathway in which overhead irrigation is prioritised on suitable soils where water entitlements are secure, and furrow irrigation is deployed selectively in locations that have stable access to surface-water infrastructure and favourable soil conditions.

Ultimately, the strategic question for policymakers and investors is not whether cotton can grow in the DRC; it clearly can, but whether it can do so in a way that is economically resilient, environmentally responsible, and socially legitimate. Based on the evidence presented, the answer is cautiously affirmative: cotton can be part of the DRC's agricultural future, provided development prioritises irrigated systems, respects water-governance frameworks, and integrates with broader

land-use, ecological, and community objectives. This balanced and compliance-oriented pathway offers the best opportunity to realise the economic potential of cotton while safeguarding the environmental and cultural values that define the DRC.

5 An Overview of Crop Production and Water Use Efficiency in NT: Implications for Daly River Catchment

Authors: Ronju Ahammad and Kamaljit Sangha

5.1 Executive Summary

This report presents baseline information on crop production costs, economic performance, and water use in Northern Territory to provide a reference for determining future water use efficiency in the agriculture sector of the Daly River catchment. By undertaking a desktop review on the selective crops, mango, watermelon and Asian vegetables, and hay, the report outlines information on the production input costs and water use and discusses their economic performance in terms of cost-effectiveness and water use efficiency. The review findings reveal higher crop performance for horticulture crops, with mango maintaining steady productivity and achieving net cash flow over input costs.

Annual crops like watermelon and Asian vegetables are more price-sensitive, affecting their continuous productivity. Compared to annual crops, rainfed hay is relatively cost-effective and performs better economically. Higher input costs, mainly for harvesting labour, marketing, and freight, affect the productivity of all crops, particularly watermelon and vegetables. Water consumption is relatively high with the tree crop mango, and it also requires long-term infrastructure development for irrigation. Overall, horticulture and rainfed hay production are efficient; however, given the groundwater dependency in the Daly catchment, any alternative, cost-effective irrigation has yet to be identified and implemented. Surface water irrigation is recommended but integrating it with the existing irrigation infrastructure and balancing it with demand and potential agricultural expansion would require further on-the-ground validation and scientific assessment of the future water flow. Effective engagement of growers, with a clear understanding and perception of the socio-environmental benefits of water resource management is recommended to achieve the goals of the new water initiative.

5.2 Introduction

The Daly River Catchment covers 5.2 million ha, from the coastline south-west of Darwin to 250 km inland and is one of the major tropical river systems in Australia (Barton and Pantus 2010). The catchment includes the major tributaries of Katherine, King, Fergusson, Douglas, Edith and Flora Rivers. Major land cover in the Daly River Catchment area is grazing pastures, with over half of the land covered (2.8 million hectares) with native vegetation and small areas with modified pastures (Adams *et al* 2016). A quarter of the area under Indigenous lands for traditional use (or under managed resource protection) (Figure 5.1). Another 20 percent of the land area is under nature conservation area (conservation and natural environments, national parks). Water bodies including wetlands and rivers share only 5 percent of the area in the catchment.

Cropping including rainfed (mainly hay and sileage), irrigated cotton and horticulture shares less than 2 percent of the area in Daly River Catchment. Eighty percent of water is sourced from ground water and primarily used for agricultural purposes. Rainfed hay and sileage production is 35,381 hectares and horticulture accounts for 3,635 hectares of land. The Daly River catchment is an important agricultural region in the NT and is particularly well-known for mango production. The region annually produces nearly 3.5 million trays of mangoes. The economic value of horticultural commodities in the Northern Territory (NT) was worth $291 million/yr with main crops grown including mangoes, melons, vegetables and grapes, among others (Sangha *et al* 2022a).

The Daly River is culturally significant for Indigenous peoples, with 12 Aboriginal groups living here. Indigenous sacred places are associated with rivers, tributaries, and groundwater-dependent ecosystems. Aboriginal people view the water as sacred, elemental sources and symbols of life and there are ceremonial tracks along the river (CSIRO 2009).

Total population in the Daly region is 11,545 (including Daly and Katherine Statistical Area as per Australian Bureau of Statistics [ABS] (2021) with 9,660 persons in Katherine and 1,886 in Daly. Nearly 80% of the population in Daly is Indigenous peoples, and 40 percent of the total population in Katherine. Nearly half of the population are engaged in labour force with relatively more working people in Katherine area than Daly area. The only towns in the Daly River catchment are Katherine, Pine Creek and Naiyu (Daly River).

This report aims to present the baseline for production costs and water use of selective diverse crops in NT and guide the future implications for water use efficiency in the agriculture sector on the Daly River Catchment. Key crops, i.e. mango, watermelon, Asian vegetables, and hay production, were used to provide the baseline information about input costs and the water use required to produce them and the feasibility of growing those crops in the region.

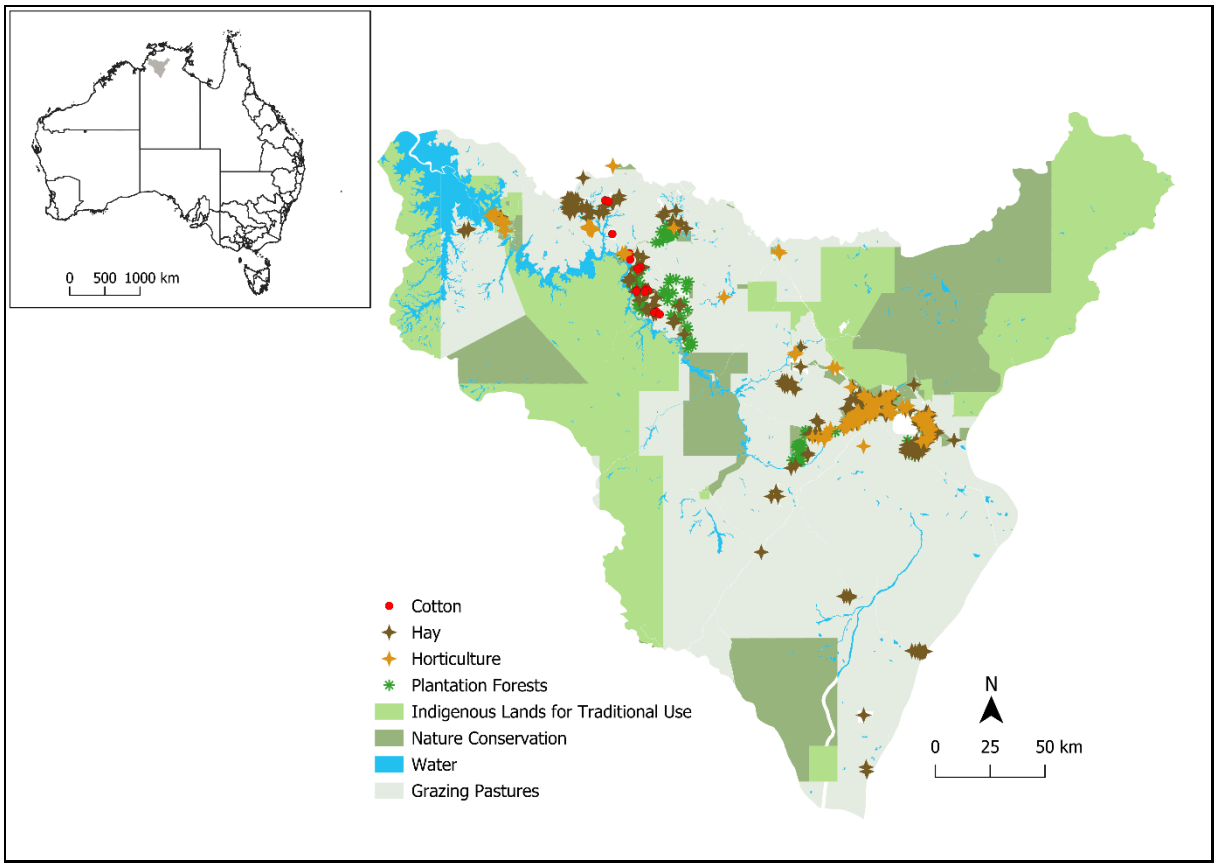


Figure 5.1. Major land use of Daly River Catchment and approximate distribution of the cropping practices for cotton, hay, horticulture and plantation forests

5.3 Methods: A desktop review

By undertaking a desktop review, this report draws the baseline information on crop production and water use within the broader NT context, which also applies to the Daly River Catchment. Five

cost items are common in farm-level production: variable costs, overhead costs, financial costs, personal costs, and capital costs that we have considered for the cost analysis. Variable costs, also called “input costs” in farm production include sowing, seed, fertiliser, irrigation water, among others. Overhead costs are those that generally do not change, like permanent wages, farm insurance, repair and maintenance, utilities, etc. Finance costs for most farmers typically include interest payments on term loans, equipment finance, and overdrafts. Personal costs include family drawings, and capital costs encompass expenditures such as the purchase and/or development of land, buildings, machinery, and principal repayment of debt. To understand economic performance and water use efficiency of cropping systems in the Daly catchment, this review considered variable costs, including marketing and water use/irrigation, to compare gross margin estimates across different water requirements for the selected crops. The report also outlines specific risks for production and water security/water allocation, as well as challenges related to climate change, markets, and supply chains.

The desktop review covered peer-reviewed literature, institutional publications (mainly from the Northern Territory Government (NTG), the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Commonwealth Scientific and Industrial Research Organisation (e.g., CSIRO 2018), Cooperative Research Centre for Developing the Northern Australia (CRCNA) and growers’ reports (e.g., NT Farmers Association). The literature search was conducted using Google Scholar and Google. For peer-reviewed literature, we used the search term for specific “horticulture” OR “mango” OR “melon” OR “Asian vegetables” OR “hay” AND “NT” in Web of Science. No suitable literature on horticulture production related to economic performance was found in the NT context in Web of Science. Then we restricted the search with the broader topic “horticulture and/or specific mango, melon, Asian vegetables and hay production in NT” in Google Scholar and Google search that allowed us to identify peer-reviewed and non-peer-reviewed, mainly institutional documents.

No specific literature exists on horticulture crops, production and economies in the Daly River Catchment. In the absence of specific literature for the Daly River Catchment, we considered studies on the selected crops from other growing regions in NT, including Darwin and Katherine, as well as Far North Queensland (crops grown in a similar environment e.g. Bennett and Dickinson 2021). While information on mango was relatively more available than for melon and Asian vegetables, production costs were specifically cited from the NT Farmers Association, ABARES’ estimate of vegetable production in Australia, and a previous CSIRO and CRCNA study, all adjusted to the NT context.

In the literature, we mainly examined baseline information for each crop, including production costs at farm establishment, detailed annual variable/input costs (e.g. nutrition, pest and disease management, irrigation, labour, harvesting, packing), and irrigation water use (ML/ha). Based on the review, information on crop production, water use, and gross margin was summarised for crops grown in NT, mainly mango, watermelon, hay, and Asian vegetables. We outline the input costs required to produce the crops, the amount of water used, and the risks/feasibility of growing the crops. Our purpose was to evaluate the crop production costs and economic performance. The baseline information on costs, gross margin, and water use is indicative, as it is sourced from the existing literature in the NT context or similar contexts in northern Australia.

5.3.1 Limitations of the review analysis

In the review of input costs, gross margin, and water use, overall caveats are noted due to the lack of recent data, and the estimate may be lower due to inflation. Specifically, input costs for Asian vegetables are unavailable in the NT context. The full account of NT’s vegetable production is not available in the Australian Bureau of Statistics, which results in a lower value of annual vegetable production compared to the estimate of the local growers’ association, i.e. NT Farmers

Association. Another discrepancy can be noted in the water use (ML/ha/yr) information for watermelon and vegetables across the sources (e.g., Department of Primary Industry and Fisheries 2025 and Webster et al. 2025).

5.4 Findings on crop production cost, water use and economic return

5.4.1 Mango

NT's mango industry shares 51% (~37,000 t) of the country's domestic supply (total ~73,000 t) in 2024-25 (Hort Innovation 2025). Around 7,120 ha are currently under mango production in NT with the average size of a mango orchard for commercial production is 15–40 ha. Table 5.1 summarises the indicative baseline costs of mango production, water use, and gross margin. High capital investments for establishing the mango farm are identified, including half of the costs for long-term irrigation infrastructure and regular overhead costs (Table 5.1). The estimate represents the establishment and capital cost and annual variable cost of the conventional low-density tree orchard (166 trees/ha and mature trees for harvesting over 5 years old) for NT (adopted from Ngo, 2002). Water use information for the Darwin region is drawn from available estimates of water use (NTG 2025; Webster *et al* 2024).

Assumption of Irrigation water is 7.8 ML/ha/yr and running costs of $300-600/ha/yr, depending on the size of the dense tree orchards. On average, capital costs (mainly land purchase and development of building, plant and equipment, including irrigation system) per hectare of mango orchard are $62,194/ha at the baseline in the first year. Over half of the annual variable costs $15,854 (62%) constitute the harvesting and freight-related expenditures. The estimated total gross income of mango is $23,934/ha/yr, just above the annual variable costs of $15,854/ha/yr, resulting in a net income of $8,080/ha/yr. With increasing trees around 207/ha and yield up to 14-15t/ha, or a price $24 per tray, the production would be profitable and above the negative return. Break-even prices are minimum prices which will enable annual income to just equal the total production costs (i.e., variable costs plus fixed costs including depreciation). Break-even prices for mangoes can range from $13.60 to $15.70/tray, or $18/tray at an expected medium yield of 9.3 t/ha.

Table 5.1. A baseline of production costs, gross margin and water use of the mango tree crop in NT

Item (Unit)		Mango
Income	Production (t/ha) (median)	9.3
	Trays/ha	1,330
	Price ($/tray)*	18
	Gross income ($/ha/yr)	23,934
Variable costs	Field costs** (Fertiliser application, Weed control, Pest and disease control, Topping/pruning, Flowering management, Irrigation and power, Repair and maintenance of power and irrigation systems) ($/ha)	3,112
	Harvesting and freight ($/ha)	9,870
	Commissions and levies ($/ha)	2,872
	Total variable costs ($/ha/yr)	15,854

Capital costs	Establishment costs (Surveying, Land clearing, Planting, Fertiliser, Weed and pest control) ($/ha)	2,778
	Land, Fencing, and Building storage room, packing shed ($/ha)	29,167
	Plant and equipment including bore and irrigation system ($/ha)	30,249
	Total capital costs ($/ha)	62,194
Overhead costs	Total overhead costs ($/ha/yr) (Accounting, Sundries/contingencies, general repair and maintenance, telecommunication)	2,631
Gross margin	Net cash flow ($/ha)***	8,080
Irrigation water	ML/ha/yr	7.8****

*7 kg tray.

**Field costs referred to the mature orchard at the time of harvesting (9-10 yrs) to compare the gross income.

***Gross margin is the difference between gross income and total variable costs.

****Annual irrigation costs ~$300/ha/yr to $600/ha/yr at the mature tree orchard. The estimated irrigation ML/ha is indicative and ranges from 3.2-7.8 ML. 1 Megalitre equals 1,000,000 litres.

5.4.2 Watermelon

Fresh watermelon is the second-largest horticultural crop in NT, after mangoes, in terms of farming area, economic value, and production volume. About 1,200 ha are cultivated with melon in NT, with an annual production of 52,980 t (25% of the domestic gross production) and an economic value of $54 million (Hort Innovation 2025). Watermelons (*Citrullus lanatus*) can be grown throughout the year in NT and especially during the wet season when vegetable varieties are limited and can be easily planted out on the land (Agnote 1999). Table 5.2 presents the indicative baseline costs of watermelon production, gross margin and irrigation/water use adopted from Ngo (2004). Assumptions of water use is 3.5-4 ML/ha, and average irrigation cost is ~$350/ha with $100/ML.

Key production cost of watermelon includes variable costs which share 88% of the gross income and a lower gross margin/net cash flow per hectare in melon production. The price assumption of melon can range from $0.45/kg to $0.90/kg by improving the gross margin to double. Mainly annual variable costs $9,932.61/ha rather than any long-term capital investment required in melon growing and harvesting. Harvesting and freight cost share 60% of the variable costs in melon production. 20% of the variable costs are related to growing costs for land preparation, seed, irrigation, fertiliser application, and insect and disease control. The break-even yield of watermelon at Southern markets is $546/t for 30 t/ha (Department of Primary Industries 2013).

Table 5.2. A baseline cost of production and irrigation/water use and gross margin of Watermelon.

Item (Unit)		Watermelon
Income	Production (t/ha) (median)	25
	Price ($/kg)	0.45

	Gross income ($/ha/yr)	11,250
Variable costs	Field costs (Establishment of cover and main crops, Mulch and drip tape laying, planting, fertiliser application, Weed control, Pest and disease control, Topping/pruning, Irrigation and power, Bee hire, Drip tape removal, Contingencies)	2088
	Harvesting and freight	6165
	Commissions and levies	1680
	Total variable costs ($/ha/yr)	9933
Capital costs*	Establishment costs ($/ha)	NA***
Overhead costs	Total overhead costs ($/ha/yr) (Accounting, Sundries/contingencies, general repair and maintenance, telecommunication)**	500
Gross margin	Net cash flow ($/ha)	1317
Irrigation water	ML/ha/yr	3.5

*Ngo (2004) did not account for establishment costs separately but mentioned seedbed preparation, seeds/seedlings under the variable costs. Lennon (2017) estimates that with a capital expenditure of $25-$30,000/ha, an annual operating cost of $50,000/ha in melon production, the annual gross revenue ranges between $30,000-$65,000/ha, with a net cash flow of $4,000-$10,000/ha.

**5% of variable costs assumed to estimate overhead costs.

***NA- Not available. Assumed land already purchased and prepared, so establishment costs include cover crop establishment (~$75/ha) included under 'variable costs'.

5.4.3 Asian vegetables

NT's vegetable production area covers ~1,000 ha with an estimated gross value of $61 million. Asian vegetables account for 90 per cent of production and value, including main crops such as snake beans, okra, long melons and other Asian melons, lettuce, cucumber, tomato, zucchini, pumpkin, and chilli (Lee 2005; Truong 2004). Among the growers, the largest vegetable producers are Asian gourds, bitter melon, okra and snake beans. Major vegetable cultivation areas include the greater Darwin region, focusing on Asian vegetables like okra, snake beans, and Asian melons, and the inland areas around Katherine and central Australia, where pumpkin and garlic are predominant. Most family-operated vegetable farms are less than 5 hectares, while commercial cultivation could range up to 50 hectares.

NT's vegetable production is relatively small compared to that of southern states and shares 5% of Australian Asian vegetable production. Table 5.3 presents the indicative costs of vegetable production, gross margins, and water use for the reference crop, i.e. capsicum in NT (Webster *et al* 2024). Following Ngo (2004), the assumption of water use of annual crop from 3.5-4 ML/ha and average irrigation cost ~$350/ha with $100/ML). Mainly variable costs are related to land preparation, growing, harvesting, and marketing of vegetables estimated at $71,000/ha/yr. The annual variable costs account for over 90% of gross income. Within the variable costs, harvesting and freight-related expenditures share 68% of the variable costs. The annual gross margin of capsicum is $4,100 per hectare per year, which can vary depending on the crops and price.

Table 5.3. A baseline cost of Asian vegetable production, gross margin and water use

Item (Unit)		Asian vegetable
Income	Production (t/ha) (median)	32
	Price ($/8kg cartoon)	19
	Gross income ($/ha/yr)	76,000
Variable costs	Field costs (Preparation of lands, seeding, fertiliser application, Weed control, Pest and disease control, Irrigation and power, labour)	22,300
	Harvesting and freight	49,600
	Commissions and levies	NA
	Total variable costs ($/ha/yr)	71,900*
Capital costs	Establishment costs ($/ha)	NA**
Overhead costs	Total overhead costs ($/ha/yr) (Accounting, Sundries/contingencies, general repair and maintenance, telecommunication)	NA
Gross margin	Net cash flow ($/ha)	4100
Irrigation water	ML/ha/yr	3.5

*No recent data available on Asian vegetable production cost in NT. Variable costs may be higher for capsicum than for Asian vegetables.
**NA- Not available.

5.4.4 Hay

NT's hay production covers 20,000 ha under rainfed conditions and produces 80,000 tons of hay worth $20 million (NT Farmers Association, 2015). Rain-fed hay is an economically viable production system in the Daly Catchment area. Rain-fed hay consists of jarra grass (*Digitaria milanjiana*) and cavalcade (*Centrosema pascuorum*) legume hay mixes that can generate a net return of $600/ha (priced at $250-300/ton and $180-200/ton, respectively) (North Australian Agribusiness Management, 2016). The main hay production area covers the Katherine and Douglas-Daly regions, as well as a small growing area in Central Australia and the Litchfield regions in the NT, with the main sources of water being rain-fed and irrigation. As a rotational crop, the availability of land and seasonal rainfalls are conducive to increasing the production volume in NT. Table 5.4 presents a summary of the costs of irrigated hay production, gross margin and water use following Webster *et al* (2024). Irrigated hay can produce above 30 t/ha to 44.7 t/ha annually.

Rhodes grass hay generates a gross margin above $4,000/ha/y which is above the net cash flow $2,000/ha. Irrigated water use requirement from 20 to 25 ML/ha for each year. The crop can be grown during the dry season, with the wet season mung bean grown in December and harvested in April. While the table did not provide the rainfed cost, but the available source provides the

evidence that rainfed hay generates $600/ha compared to $2,000/ha. Almost three times more of rainfed the net return is possible by integrating irrigated hay, e.g. jumbo sweet sorghum.

Table 5.4. A baseline cost of irrigated hay production, gross margin and water use with the adjustment for Rhodes grass grown in Victoria Catchment, NT

Item (Unit)		Irrigated hay
Income	Production (t/ha)	44.7
	Price ($/t)	$220
	Gross income ($/ha/yr)	9,827
Variable costs	Field costs (Preparation of lands, seeding, fertiliser application, Weed control, Pest and disease control, Irrigation and power, labour)	1,680
	Harvesting and freight	3,570
	Commissions and levies	NA*
	Total variable costs ($/ha/yr)	5,250
Capital costs	Establishment costs ($/ha)	NA
Overhead costs	Total overhead costs ($/ha/yr) (Accounting, Sundries/contingencies, general repair and maintenance, telecommunication)	NA
Gross margin**	Net cash flow ($/ha)	4,577
Irrigation water	ML/ha/yr	24.8

*NA – Not Available.

**Rainfed hay net cash flow is $600/ha.

5.4.5 Key findings on production cost and water use

Among the crops, the perennial crop mango has a relatively higher gross margin ($8,080/ha), followed by irrigated hays ($4,577/ha) and vegetables ($4,100/ha) (Table 5.5). Melon produce has been estimated to be lower margin $1,317/ha than all other crops. While horticulture crops are generally price-sensitive, its impact on economic performance can be relatively greater for melons, leading to negative returns. Market price variation from 50% decline to a 100% increase could result annual gross margin of melons falling to –$20,496/ha to rise $25,017/ha (Webster *et al* 2024).

Table 5.5.5. Comparison of annual water use, variable costs, gross margin for perennial (mango) and annual crops (watermelon, vegetables) and hay production

Crops	Water use-Micro irrigation (ML/ha/yr)	Crop yield (t/ha/yr)	Price ($/unit)	Pricing unit	Variable costs ($/ha/yr)	Gross income ($/ha/yr)	Gross margin ($/ha/yr)

Mango	7.8	9.3	18	7 kg tray	15,857	23,934	8,077
Watermelon	3.5*	25.0	0.45	per kg	9,933	11,250	1,317
Asian vegetables (e.g. Capsicum)	3.5	32.0	19	8 kg carton	71,900	76,000**	4,100
Hay	24.8 ***	44.7	220	ton	5250	9,827	4,577

* Department of Primary Industry and Fisheries (2025) reported water use of watermelon 6 ML/ha/yr and Asian vegetables up to 9 ML/ha/yr.

**No data available on the production cost of Asian vegetables in NT. The estimate for capsicum may be higher compared to Asian vegetables.

***Not specified but assumed pivot irrigation

Variable costs influence economic performance, which are higher for vegetables ($71,900/ha, 90% of the gross margin) and melon ($9,933/ha, 88% of the gross margin) than for mango ($15,854/ha, 66% of the gross margin). Only irrigated hay production costs are relatively small, $5,250/ha (53% of the gross margin), compared to any other crop. From a long-term cost perspective, mango requires much higher production costs than any other crop due to its long-term investment in land, infrastructure (including housing), labour, shade, storage, and irrigation facilities. The total investment costs of mango/ha (600 tree/3.61 ha orchard), including all capital costs ~ $101,733 which is double than $42,902/ha for 3,000 tree orchard The payback period for the capital investments exceeds 16-20 years. The harvesting commences only from the 3rd year or later at early maturity of trees, but the positive net cash flow can be assumed only from the 7th year.

Overall harvesting and freight costs account for over 60% of the annual costs in any of the horticulture crops and hay production affecting the margin and the net return. Asian vegetables require much of the expenditure for harvesting and freight $49,600/ha including high overhead cost per unit of production especially for family-operated growers, fluctuating input cost, mainly fertiliser price.

5.4.6 Water use efficiency

Mango requires more water (7.8 ML/year) than annual crops (Watermelon: 3.5 ML, Asian vegetables: 3.5 ML) or rainfed hay. Perennial horticulture crops including mango irrigation occurs for a longer period each year. In early years of mango plantation (year 1-2), the orchard requires intensive irrigation 40 weeks per year. Since the 3rd year, the irrigation rate has been 10 weeks per year. With the increase in tree canopy volume, the irrigation increases every three to four years in the mango orchard. Irrigation system must ensure delivery of sufficient water for the crop peak requirements, e.g., fruiting, quality of fruit. However, mango responds to a dry period by flowering earlier and more profusely than would otherwise occur if they were continually irrigated.

Annual crops watermelon and vegetables are particularly water dependent for a shorter time period of the growing season in the dry season. While water consumption is relatively lower than in perennial systems, irrigation is critical to ensure water availability for crops that are profitable during the seasonal window.

Asian vegetables and rainfed hay production are water use efficient as opposed to mangoes and other perennial crops like lime, grapes, which require higher security water. The existing rain-fed hay production is highly efficient, but for achieving high yield and quality there is potential to expand irrigated fodder production with sudax/sorghum varieties and Rhodes grass. Irrigated hay production can be also demanding in the dry season when the quality and quantity of native

pasture decrease and there is increased demand for livestock dietary supplements as well as pellet production; however, the only constraint would be the higher water dependency.

5.5 Discussion and Conclusion

5.5.1 Economic performance

This review finding supports that the gross margin of horticulture crops is higher (~7,000/ha/yr) than that of broadacre crop like cotton or hay production (i.e. ~$4,000/ha/yr). A study on the historical estimates revealed that the horticultural sector in NT and other northern regions of Australia (far-north QLD and northern WA) has been quite efficient, with their selective commodities continuing to drive the trend over the past years (NT Farmers Association 2015). Farmers can be said to be highly efficient in producing large quantities of mainly mangoes and melons (Sangha *et al* 2022a). Vegetable production predominantly represented by Vietnamese and Cambodian growers has shown growth over the past 15 years by supplying the traditional Asian vegetables to the local and domestic market (Hort Innovation 2019).

Among others, mango has relatively more stable gross margins and thus economic viability than other horticulture crops or hay. The review finding indicates that the net cash flow of mango is well above the minimum of $4,500/ha/yr. Considering the conventional low-density trees in NT (~200 trees/ha orchard) and yield (18 t/ha), the annual gross margins/ha could be achieved at $15,000 in 6 years old trees to ~$20,000 ha/yr of matured orchard in 11 years (Bennett and Dickinson 2021). Since mango is relatively capital-intensive due to its high initial establishment costs for land purchase and development, the rapidly increasing yield per hectare of lands can amplify the gross margin to maintain economic viability to pay for the capital cost.

Another determinant of economic performance is seizing the narrow market and price windows in southern markets such at Melbourne, Sydney, Brisbane, Adelaide, and Perth. Early production of mangoes of premium quality, with strong demand in the domestic market thrives the commodity and marketing the produce during the narrow price window is a great leverage. NT growers produce half of the Australian mango (51%) while strong seasonal market remain critical for the economic viability of the crop. Harvest of mango in NT is earlier than in any other northern state, and thus the growers have secured a market premium for the commodity for a long time. Major melon growers in Australia are also located in NT. Over the past years, Asian vegetables have been a well-established industry for small growers as a reliable and year-round farming. The dry season production of vegetables is a great advantage for the growers in NT.

5.5.2 Cost-effective production

Horticulture crops require a higher range of gross margins ($7,000-11,000/ha/yr) to cover production costs and maintain profitability (Stokes *et al* 2018) and the current review finding only supports for mango to be efficient. Mango is the only high-value agricultural produce in NT after beef production that the growers can ensure cost-effective production and profitability, as stated earlier, by increasing the yield over the years despite the fact to the high initial investment costs.

Rainfed hay can be cost-effective for no irrigation requirements although the dry season demand for the feedstocks would be higher which cannot be met without the expansion of irrigated hay like Rhodes grass. Irrigated hay can be integrated with rainfed through cropping during the early Dry (April-November), which can allow the growers to increase cattle numbers and reduce costs for external feed sources. Further study and ground evidence on rainfed and dry/irrigated hay can reveal the full production potential.

Annual operating costs affect cost-effective production due to input costs for fertilisers, pesticides, and transport challenge the sector's profitability and economic sustainability of all crops. Labour, harvesting, and supply chain (freight, market) costs are dominant costing issues across all crops in NT that are relatively more challenging for vegetable growers to manage (Sangha *et al* 2022a). Any cost fluctuations of those inputs affect the annual crop production of melons and vegetables, in addition to price sensitivity, resulting in lower and negative profit margins. The competitiveness of the specific vegetable industry will require improving productivity and reducing costs through the supply chain. Low development costs would be required for annual crops like vegetables to be profitable.

Marketing the produce during the narrow price window is a great leverage, but a long supply chain and competition within the domestic market for similar produce from other states/territories constrain the economic profitability of growers in NT. Transportation time and following market protocols lessened the grower's ability to maintain a consistent supply of the produce. This short market window can affect the production of any growers, especially small growers, as it makes it difficult to maintain a consistent economic return or profit margin. Long-distance transport, managing the quality of the produce during transport, and awareness of market conditions can affect all crops except mangos.

The size and scale of production (volume) leverage mango and melon to offset costs and achieve economic returns relative to vegetables in NT. The existing scale of Asian vegetable production affects cost efficiency and gross margins. Farmers growing less than 5 hectares of land incur four times the cash cost per ton of vegetable production compared to those growing more than 5 hectares. A nationwide comparison shows that only 2% of NT's vegetables were reported in the southern market for specific types, such as pumpkin (2086 t in NT compared to 110,561 t at national level) and leafy Asian vegetables (586 t compared to 27,604 t) in 2025 (Hort Innovation 2025). While some vegetable growers establish mixed Asian vegetable and tropical fruit crops like rambutan, the market for the latter is a niche. The availability of family labour is often an important determinant of cost management and profitability for labour-intensive crops like the Asian vegetables.

5.5.3 Water use efficiency

Water use efficiency is closely linked to crop types, farm size, and soil conditions in NT. Perennial horticulture crops like mango and others (grapes, limes) require a reliable, long-term entitlement to water use, compared to annual crops. Mango typically requires more water (7.8 ML/ha/yr sourced from groundwater with sprinkler) than annual crops like watermelon (3.5 ML/ha/yr) and vegetables (~3.5 ML/ha/yr) because the tree crop occurs for a longer period each year. Specifically Asian vegetables or hay (forage crops) can thrive under low water security and they can adapt to various conditions of water availability, e.g. temporary water use by the growers in trade agreement with another water license holder/sellers (Department of Environment and Natural Resources 2020).

Despite watermelon requiring high water security due to a relatively short life span (10–20 weeks), reliable water is required for the vegetable farms located near suburban areas that rely on reticulated or town water supplies. Overall compared to other annual crops, hay production can be said to be water use efficient under rain-fed conditions when it does not require additional irrigation water.

Irrigation in the Daly catchment is highly groundwater-dependent with a pivot distribution generally considered water-use efficient. Given the sandy soils in the region, pivot irrigation systems are highly efficient at applying water to most field crops and across all land topographies. Specific to highly valued horticulture tree crops, i.e. mango, which demand quantity and quality parameters for profitability, however micro irrigation is preferred for precision and water efficiency. As an alternative to those groundwater-dependent irrigation systems, the NT government's proposed

water policy aims to include surface water uptake during the wet season, recover unused groundwater entitlements to allow water trade and investment in furrow irrigation (Department of Environment and Natural Resources 2020; Department of Lands, Planning and Environment 2025). Although surface irrigation approaches have been well established in the southern region, such as the Murray-Darling Basin, none have yet been clearly assessed to fully explain their potential for reliable water and economic suitability at the scale of crop production in the catchment and NT.

Surface irrigation will suit most crops and incur a lower capital cost than spray or micro irrigation systems. Despite that, surface irrigation systems and furrows are not highly efficient in the Daly catchment and NT due to sandy soils, high seasonal rainfall, significant evaporation rates (annual potential evapotranspiration exceeding annual rainfall) and high storage costs (CSIRO 2009). Poor soil drainage and secure groundwater in the late dry season remain a challenge for growers in the Daly Catchment. Further evaluation of the design of surface water infrastructure will help compare with the predominant groundwater-based irrigation system and assess the feasibility of any integrated implementation in the catchment.

In line with the national water initiative and the water entitlement practices in southern basin states, for the first time, the NT government proposes a new water charging framework comprising an annual licence fee (managing water licences) and a volumetric (per ML) water charge by 2032 (Northern Territory Government 2023). While this significant policy change will contribute to recovering the government's water management costs (i.e., the annual licence fee of ~$100-500), it primarily promotes water efficiency and industry competitiveness. As per the proposed framework, the volumetric water charge would be a uniform per ML for all licensed users, with a minimum charge for lower levels of water take. However, future water charges can impact the economics of irrigated agriculture and raise concerns among growers without a clear understanding of how the costs borne by irrigators and other water licence holders are fair and affordable. The proactive engagement of the growers, ensuring the transparency and enhancing perceived benefits of how the revenue from the charges would be used for better water management and increased water licence security can offset any concerns of the growers.

Any expansion of agriculture in the Daly catchment would pose major challenges for growers, requiring them to ensure economic returns to offset the investments in irrigation. Specifically, crop expansion on a newly developed site or an established farm with existing irrigation infrastructure would determine the scale of irrigation investments, favouring water efficiency. Only horticultural crops and/or mixed crops are found to repay the investment in the new development site; however, the best option would be to expand crop production on the existing farm, with prior economic returns (hay, cattle) and irrigation facilities already in place (North Australian Agribusiness Management 2016; Webster *et al* 2024). Nevertheless, the existing farms incur irrigation costs (bores, pumps, pivots) of ~$11,910/ha, suggesting careful on-ground consideration of reliable water sources. Because the new policy of a water use charge for agriculture might affect the economics of irrigated agriculture, leading to a decline in productivity, unless an alternative measure, such as surface water, is feasible at the scale of operations and profitability, achieving water efficiency may be uncertain.

6 Strategic recommendations

Across its three streams of work, this report highlights that agricultural development in the Daly River catchment is constrained less by the physical availability of water than by the certainty and coordination that surround it. The interviews showed that where governance frameworks do not give growers confidence that water will remain available over the life of an investment, individual growers default to caution and the broader regional opportunity is deferred, whereas the more secure collective entitlements of the Ord cooperative have supported its progress toward commercial self-sufficiency. The economic analyses showed that crops can be viable in the catchment, with cotton viable under irrigated systems and several established horticultural and fodder enterprises returning positive margins, but that this viability is sensitive to the irrigation system used, market conditions, and the future cost of water. Read together, these findings indicate that the conditions for investment, secure access, efficient water use, and a coordinated economic base, matter as much as the water resource itself.

The recommendations below (Table 6.1) are framed to balance two objectives: giving growers the certainty they need to invest, and ensuring that development remains within environmentally sustainable limits. The recommendations are staged, evidence-conditional, and set up so that they could be implemented without committing to outcomes ahead of the evidence. Recommendation 1 addresses the central need for the relevant NT departments to confirm a shared position and align their settings, including the conditions under which greater investment certainty could be offered. Recommendation 2 addresses readiness for potential future water pricing, by documenting a clear plan, method and timeline for how any pricing mechanism would apply and what its revenue would fund, which strengthens both grower certainty and the evidence base for sustainable allocation. Recommendation 3 addresses the relationship between growers and government by planning a revised multi-stakeholder advisory committee for the catchment, modelled on the former Daly River Management Advisory Committee (DRMAC) but re-scoped to give irrigated growers direct representation. The catchment has a precedent for the kind of body proposed in Recommendation 3. DRMAC, previously brought together government, landowners, Traditional Owners, and recreation, fishing and conservation interests, and its objectives guided catchment planning that explicitly weighed agricultural development against conservation and cultural values (Adams, 2015; Adams and Pressey, 2014). A future committee would need to reconcile, reinforcing the value of a standing forum in which those differences can be worked through transparently.

Taken together, the recommendations are intended to enable sensible and environmentally sustainable development.

Table 6.1: Project recommendations

Key priority actions for sector development	Action owner and key partners	Pathways to implementation and timeline	Intended industry impacts
DAF and DLPE to document shared position to align licensing and planning. Where monitoring confirms allocations are sustainable, mechanisms for greater investment certainty, including access longer than the current ten-year term, are assessed and trialled on the evidence.	**Department of Agriculture and Fisheries (DAF) and Department of Lands, Planning and Environment (DLPE)** Partners: Growers, NT Farmers Association, Traditional Owner groups and land councils.	Establish a joint DAF and DLPE working group and publish a unified position by the end of 2027. Work to embed agreed settings in upcoming relevant water allocation plan reviews.	Greater investment certainty and improved capacity to use water access as finance equity. Conditioning certainty on monitored sustainability maintains environmental and cultural safeguards.
Remove the uncertainty around volumetric water pricing by documenting and publishing a clear plan for whether, when and how a price would apply, including the proposed method, the timeline, and what the revenue would fund, such as metering, monitoring and compliance capacity	**Department of Lands, Planning and Environment (DLPE)**. Partners: Department of Agriculture and Fisheries, NT Farmers, growers.	Research pricing options and model enterprise-level impacts, drawing on the cotton sensitivity analysis (Appendix B, Table 8.2), in years 1 to 2. Publish a plan setting out the method, staging, timeline and revenue use, developed with growers.	Growers can plan against a known pricing outlook rather than uncertainty. Setting out what any revenue would fund shows growers what they receive in return, and links pricing to the monitoring that underpins sustainable allocation (Recommendation 1).

Re-establish a Daly River Management Advisory Committee, a standing multi-stakeholder body. Plan a revised committee of to bring government, growers, Traditional Owners and other catchment interests together, re-scoped to give irrigated growers direct representation and a defined role, with a documented process and published advice and responses.	**Department of Lands, Planning and Environment (DLPE)** and **NT Farmers Association**, Department of Agriculture and Fisheries, Traditional Owner groups and land councils, growers, researchers.	Scope and establish the committee within 18 months, with representation including irrigators and commodity groups through NT Farmers' regional councils, Traditional Owners covering the Daly's reaches, and the relevant government portfolios. Define its role in the five-year reviews and publish its advice and government's response from the outset.	A recognised, standing channel between growers and government reduces the distrust that currently deters investment. Transparent, consistently applied process gives growers the confidence to commit, helping shift the region from caution toward long-term investment.

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8 Appendices

8.1 Summary of the Interview Output Conducted in the Douglas Daly Region

This section contains additional details from the interviews that relate to the Douglas Daly region. The results presented in Section 3 include an assessment of interviews with growers both in the Douglas Daly region and the Ord River Irrigation Area.

Introduction

Agricultural development in the Douglas Daly region faces environmental and socio-economic challenges Rising demand for water, compounded by climate change, exposes growers to risks around water security and crop productivity, and complicates land management. Policy makers and regulators seek to balance environmental conservation with agricultural development through water licences and allocation policies.

To understand the impact of these water policies and allocation strategies on growers, semi-structured interviews were conducted with landholders in the Douglas Daly region. Growers, suppliers and contractors were interviewed about how water policies affect water-dependent agricultural activities.

Methods

Interviews were completed in the Douglas Daly and Katherine region with five landholders and an industry representative over September to December 2025. The interviews were conducted under an ethics approval granted by Charles Darwin University, Australia, number H25002.

Prior to the commencement of the interviews, an interview guide was developed to guide discussions. The guide included mapping out the interview type, key themes, and related logistics and approvals. The semi-structured interviews with landholders in the Douglas Daly region revolved around the following key themes:

- water entitlement and supply,
- markets,
- human capital,
- supply chains and
- infrastructure and policy settings

This thematic guide provided a framework for discussion, with the question order and depth of exploration varying according to the participant responses, expertise and experiences. This conversational method encouraged landholders to share their perspectives and experiences in their own terms, while the interviewer used prompts and follow-up questions to ensure all five areas were adequately covered.

The semi-structured format balanced the need for comparable data across interviews with the flexibility to explore emergent themes and capture the nuanced, context-specific knowledge that landholders possess about their business operations. Interviews typically lasted between 45- 90 minutes, allowing sufficient time for rapport-building and detailed discussion of each thematic area.

Irrigators in Katherine and the Douglas Daly regions were contacted directly and asked whether they wished to participate. This purposive approach suited the small, dispersed population of irrigators in the region. The researcher met participants on-farm, or in one case in town, to minimise inconvenience. Because the interviews were conducted in December 2025, at the start of

the wet season and the end of the mango season, some potential participants were already away and could not be included.

The interviews are summarised with recurring themes and presented in section 3 below. Key themes are split into two main groups: those that are related to water and how water is managed and allocated, and other non-water-related factors that influence farming operations and decisions.

Results

A summary of the main water-related issues and non-water-related issues are provided below. The implications of these issues are then discussed in more detail in the short discussion.

Water-related themes

Water entitlements and supply are the only topics discussed under the water-related theme. The topics and the associated pain points raised by the participants are presented in Table 8.1.

Table 8.1 The water-related theme with the associated pain points identified by the interviewees

Pain Points	Summary of Concerns Raised
Security and duration of access	Licence Tenure Challenges with the 10-year licence tenure. The short-term licensing impacts on business expansion and commercial certainty. Licence Review Timeframe Growers note that the 5-year review does not support development that would allow small landowners to raise the capital needed for their businesses. Licence Renewal and Approval Prolonged timeframe to renew water licenses, which can lead to delay or no reallocation of licenses when they expire. Licence Allocation Some participants stated that the 8ML/ha of licences being issued is not enough for business expansion. The 50% reduction in allocation is considered severe by growers. Longer security is required such as the WA 30 years. Low- and medium-level supply security is not being prioritised. Slow and steady development is not well supported, especially the implementation of the “Use it or lose it” approach. Bundling of water and land rights were discussed by some participants, with diverging opinions on bundling water and land rights.

Transparency and process concerns	Growers complained about the difficulty of renewing their licences. Difficult to know what the process is for the 5-year review and what will be carried out at 10 years, as it is not transparent. Some participants noted that the capacity to implement priced water and monitor metering is lacking.
Financing	Banks are looking to value water licences but currently don't have a formal valuation process. High costs in organising pivots and drilling, resulting in higher operational costs.

Other, non-water-related themes

The non-water-related theme comprises four key topics that have been identified to contribute to crop productivity

Table 8.2. The non- water-related factors affecting landholders and crop productivity, as identified by participants

Topics	Concerns Raised
Infrastructure	Supporting infrastructure such as roads are limiting. Unreliable Internet Access presents problems with communication and uptake of new technology. Long-term adoption of technology can be expensive.
Markets	Limited access to high-value markets. Lack of biosecurity program and the fall in cotton prices limit the viability of certain crops to meet the market demand and product specifications. Soil quality issues, affecting production.
Supply Chains and Logistics	High freight costs.
Human Capital	High staff turnover. Compliance issue regarding the PALM scheme, prohibiting growers from utilising human resources where and when it is most needed.

Discussion on water and non-water-related issues identified in semi-structured interviews

Water-related themes

A recurring pain point among all the participants interviewed was the 10-year licence term. All the growers identified this as an issue with significant impacts on productivity and commercial certainty. They argued that the short-term water licence is insufficient to support long-term planning and agricultural investment, which constrains the capital needed to expand their businesses. Commercial agriculture is capital-intensive, requiring land development, irrigation infrastructure, groundwater extraction systems, bores, storage facilities, and crop establishment. For example, one participant said that they spent ~$900,000 to relocate the pivot and make it operational, because they had to reassign it after multiple failed attempts to successfully drill bores at a particular location. Another participant noted that good bores that pump 100 L/s cost about $1,000,000 while another said that it costs $1,000,000 to implement a 50 ha pivot. One grower said that 10 years is too short (for licence duration), given there is no established crop rotation and no clearly viable cropping option. Another participant noted the difficulty in understanding the process for the licence review at five years and at the end of ten years. Participants generally agreed that the short-term nature of licences makes it difficult to secure financing for further development or expansion.

The capital access constraint is not the only issue associated with short-term licensing. The short licensing term affects crop productivity, where growers need assurance of long-term access to water to plan and produce. Some growers pointed out that the 10-year water licence timeframe does not provide confidence and commercial security. Perennial crops such as mangoes need sustained irrigation that increases as the trees mature. The growers stated that a longer licence term ensures commercial certainty, capacity for long-term business planning and expansion, and the ability to finance investment. Some participants want licences to be in perpetuity, while others want the 10-year timeframe expanded significantly. Perpetual entitlements can limit adaptive management, though active monitoring could allow allocations to be adjusted if water resources change materially. Additionally, requesting a perpetual water entitlement can be ambiguous; care should be taken to clarify whether a licence is in perpetuity or a long-term entitlement.

Property rights was also a topic that was raised by several respondents. Some growers interviewed want their water rights to remain bundled with their land, noting that unbundling water entitlements would increase administrative costs, raising operational costs and potentially placing greater financial stress on growers. One participant, however, saw an unbundled system as a positive. Others said they want licences to be perpetual to facilitate trading, though the participants who raised this noted a lack of "compliance capacity to implement priced water and to have meters checked," which left them sceptical about how the government would implement water pricing in the region. Participants also observed that the NT system differs from the southern states, and that this variability needs to be considered in reviews and policy decisions.

On balance, most participants felt it was important that water remain bundled with land. While perpetual bundled systems give growers long-term assurance, among other benefits, they also limit water trading and the market that supports it. The National Water Initiative, by contrast, prioritises the unbundling of water rights to facilitate trading and strengthen water markets. Water extraction in the NT is primarily from groundwater, and trading groundwater is more complex than trading surface water, since extraction in one location may have different impacts to extraction in another. Groundwater systems also experience water quality variations, local drawdown effects, and lags between drawdown and its impacts, all of which must be accounted for if trading is to be sustainable. One option would be discussions around caps on property rights: for example, half the

entitlement held in perpetuity and half bundled to the land. This way the system is not fully bundled, and water can be traded sustainably.

Respondents also raised concerns about the "use it or lose it" approach. Some participants were anxious about not using their full allocation, fearing that if an unused portion were withdrawn, it would not be available later when they needed to scale up production or switch to high-value crops. One participant, for example, was still working out crop rotations, and noted that timing decisions had been a major challenge for the business. Participants also said that the "use it or lose it" approach does not support slow and steady development, making investment expensive and highly risky.

A recurring theme was low confidence in government processes and decision-making. One grower recalled that licences had previously been categorised by supply security as low, medium and high, but that these categories had since been grouped together. The grower felt that a change a minister could make so readily left little security, which made it hard to commit to investment. The same grower also raised the lack of communication from the Water Department and the prolonged processing time for a water licence application they had submitted. Another participant recounted that an administrative change in 2007 required growers to return their licences, after which they did not receive their full allocations, and that development could not proceed while the matter was before the court. A further participant considered the earlier 50% reductions in licences too high, but would accept the 30% reduction recommended by the Water Advisory Committee. Allocation reductions announced at the start of the irrigation season give growers time to assess where savings can be made, though this mainly applies to annual crops such as melons, allowing those growers to adjust their operations in response to reduced allocations through the dry season.

Two further issues were raised under the water theme. The first was the absence of a formal valuation process for water licences. One participant noted that banks are willing to value water licences but have no formal process to do so, which limits the use of a licence as security for finance. The second was that low- and medium-security entitlements are not being prioritised and are not monitored, which the participant felt rendered those categories effectively meaningless.

Non-water-related themes

The points raised under this theme include infrastructure, markets, supply chain and logistics, and human capital. Several participants said that supporting infrastructure, such as roads, internet access, and proximity to services, is limiting business progress, and that operations suffer during flooding events. Because these businesses are remote, they sometimes lack reliable internet access, which hampers communication and machine automation. Some participants also noted that adopting technology can be expensive over the long term, and that a grower who has a poor experience with it is less likely to invest again. Remoteness from service providers compounds this: when a machine breaks down, it takes time to get a technician to the property for repairs.

Access to reliable markets was also discussed. Growers acknowledged that a market for their products exists, but identified several factors that can limit their ability to use established or new markets, including the absence of biosecurity programs, soil constraints, price, and profitability. Some participants noted that without a biosecurity program it is difficult to achieve high productivity and meet market specifications. One participant said the 2025 decline in cotton prices had discouraged some growers and constrained production, given that cotton is expensive to grow. Others noted that while crop rotation can improve yields, soil constraints such as poor quality and structure are limiting root development.

On supply chain and logistics, growers reported high freight and transport costs, which they attributed to the distances between farms, processors, ports, and markets. Fertiliser, for example, arrives through the Port of Darwin and is then transported to farms in the Daly and other remote areas, adding to costs. Growers also noted that refrigerated transport raises energy costs, given the long distances produce must travel across the supply chain.

Growers noted that the Pacific Australia Labour Mobility (PALM) scheme allows approved employers to hire workers from Pacific island countries. They explained that the scheme initially permitted around 304 hours over a one-to-five-week period, but that following a 2025 reform this changed to 120 hours over four weeks. One participant noted that the compliance burden is high and restrictive, making it harder to retain staff who want to work longer hours. The reduced flexibility in how growers can engage workers can affect productivity. During the mango season, for example, picking comes in waves, a large flush, then a lighter one, then another large flush, and longer hours over a longer period would let businesses match labour to harvest demand, which the stricter weekly-hour rules do not allow.

Growers also said it can be difficult to find workers with dual or multiple skill sets, such as experience in both cattle and cropping. They noted that the Territory experiences high staff turnover, driven by factors including families relocating to the southern states, better opportunities elsewhere, and the high cost of living. High turnover can reduce productivity and raise operating costs through higher recruitment and training expenses.

Summary and conclusions

Developing agriculture in the Northern Territory requires careful consideration of the diverse factors that affect both development and the socio-economic position of growers. Such consideration is increasingly important as the region faces climate variability and rising water demand, currently managed through annual allocations. While licence allocations provide a strategic framework set by the NT government, growers still face issues that affect productivity. Many perceive the short licence duration as sitting in tension with the government's own ambition for agricultural expansion. It creates uncertainty for growers, including for long-term crop planning, particularly for crops that need specific water volumes at different stages of their life cycle, such as mango orchards.

The 10-year licence tenure also has implications for trading. While water trading in the NT is at an early stage, a short tenure can limit growers' ability to borrow against their entitlements. This points to a possible middle ground between the current arrangements and the longer terms some growers seek: where the evidence shows allocations are sustainable, providing greater security of access, whether through a longer term or other mechanisms, could support business planning and give investors more confidence, without committing to a particular volume of water ahead of that evidence. Alongside any such change, establishing a formal valuation process, as some growers requested, would help banks value water licences.

Unbundling water rights is often argued to facilitate trading and strengthen the water market, as the National Water Initiative promotes. Young (2015) notes that unbundling water and creating a market can lead to more efficient water use and greater flexibility, reducing the need for measures such as the "use it or lose it" rule. Despite these benefits, growers in the region prefer bundled water rights. Unbundled entitlements can also pose challenges in areas that rely heavily on groundwater for irrigation: the groundwater market is complex, with boundary uncertainties and drawdown effects, and extraction can affect groundwater-fed rivers, including the Daly. A fully

unbundled system may therefore not be the right fit for the region, and an intermediate arrangement, retaining the security growers value while allowing some sustainable trade, may warrant exploration.

These water-related issues can be addressed through a sound governance framework grounded in scientific evidence. Timely licence reviews and renewals, together with allocations that reflect what the resource can sustainably support, shape growers' capacity for long-term planning. A measured move toward more secure access, conditional on that sustainability being demonstrated, could give growers and private investors greater confidence and support the longer-term investment needed to grow the Territory's agricultural industry, while keeping development within environmentally sound limits. Used in this way, more secure access could also give banks the confidence to lend against licences and allow growers to plan over longer horizons.

Non-water factors also play a crucial role. Reliable roads make it easier to move produce and reach essential services, particularly in remote areas. Reliable internet connects growers to wider markets and, beyond market access, supports machine automation.

Human resources matter as much to the sector as adequate water allocations and secure licences. High staff turnover adds to production costs and can mean the loss of valuable expertise. While the PALM scheme helps fill labour gaps, limited flexibility in deploying that labour where it is needed places strain on growers, who must match labour to demand. These non-water factors are costly and time-consuming to address, but the relevant government departments still need to address them to give growers and investors certainty and, ultimately, to strengthen the agricultural industry.

8.2 Sensitivity analysis of irrigated and rainfed cotton

Table 8.2 Economic performance of the modelled cotton production systems at a range of discount rates, expressed per hectare over a 20-year horizon. Columns are: Discount rate, the annual rate used to convert future cash flows to present-day terms; System, the production system modelled (for example irrigated or rainfed); PV of 20-yr GM ($/ha), the present value of the 20-year stream of gross margins (crop income less variable costs), discounted to today at the stated discount rate; CAPEX ($/ha), the capital expenditure on fixed assets such as land development, bores and irrigation infrastructure; NPV ($/ha), net present value, the discounted net cash flow over 20 years (broadly, the PV of gross margins less capital expenditure), where a positive value indicates returns exceeding the discount rate; Discounted payback (yrs), the number of years for cumulative discounted cash flows to recover the capital outlay, with values beyond 20 indicating payback is not achieved within the horizon; and EAV ($/ha/yr), equivalent annual value, the NPV expressed as a constant annual amount over the 20 years at the stated discount rate. All dollar values are rounded to the nearest $10 increment.

Discount rate	System	PV of 20-yr GM ($/ha)	CAPEX ($/ha)	NPV ($/ha)	Discounted payback (yrs)	EAV ($/ha/yr)
0.03	Irrigated – Furrow	$36,260	$15,000	$21,260	7	$1,430
0.03	Irrigated – Overhead (Pivot)	$35,750	$25,000	$10,750	13	$720
0.03	Rainfed – Single skip	$12,560	$10,000	$2,560	15	$170
0.05	Irrigated – Furrow	$30,370	$15,000	$15,370	8	$1,230
0.05	Irrigated – Overhead (Pivot)	$29,950	$25,000	$4,950	16	$400
0.05	Rainfed – Single skip	$10,520	$10,000	$520	19	$40
0.07	Irrigated – Furrow	$25,820	$15,000	$10,820	9	$1,020
0.07	Irrigated – Overhead (Pivot)	$25,460	$25,000	$460	20	$40
0.07	Rainfed – Single skip	$8,940	$10,000	-$1,060		-$100
0.09	Irrigated – Furrow	$22,250	$15,000	$7,250	10	$790
0.09	Irrigated – Overhead (Pivot)	$21,940	$25,000	-$3,060		-$340
0.09	Rainfed – Single skip	$7,700	$10,000	-$2,300		-$250
0.1	Irrigated – Furrow	$20,750	$15,000	$5,750	11	$680
0.1	Irrigated – Overhead (Pivot)	$20,460	$25,000	-$4,540		-$530

0.1	Rainfed – Single skip	$7,190	$10,000	-$2,810		-$330
0.12	Irrigated – Furrow	$18,200	$15,000	$3,200	12	$430
0.12	Irrigated – Overhead (Pivot)	$17,950	$25,000	-$7,050		-$940
0.12	Rainfed – Single skip	$6,300	$10,000	-$3,700		-$490

8.3 Cropping Systems of Tropical Northern Australia - A 40-Year Synthesis of Field Research Data

The work presented below has been prepared for submission to a suitable peer-reviewed journal. The expectation is that it will be under review by the submission of the final reports. As such, a copy of the draft manuscript is included here.

Jaba Rani Sarker, John Rolfe

Abstract

Broadacre cropping in the tropical Northern Territory (NT) of Australia presents a significant but largely unrealized agricultural development opportunity. Despite 40 years of publicly funded field research at the Douglas Daly and Katherine regions, no study has systematically evaluated all feasible double-crop rotation systems under a consistent economic framework using verified historical yield data. This paper addresses that gap. This synthesis integrates 97 verified data points from six peer-reviewed publications spanning 1984-2024, evaluating yield performance, economic viability, production risk, and capital recovery across seven crops and twelve rotation systems. Three research questions are addressed: 1) which rotation systems achieve the $2,000/ha viability threshold required to service irrigation infrastructure investment; 2) what the probability of economic failure (PEF) for each system is; and 3) under which capital conditions does investment generate a positive net present value. At current 2024-25 commodity prices, only three rotation systems appear to be economically viable: mungbean-winter maize ($2,617/ha, PEF 16%), mungbean-peanuts ($2,625/ha, PEF 23%), and summer maize-winter maize ($2,402/ha, PEF 30%). No individual crop achieves viability. Capital structure is the dominant determinant of investment outcomes: the mungbean-maize rotation generates a 20-year net present value (NPV) of −$682/ha on greenfield capital ($35,050/ha; 2024 AUD) but $19,234/ha on existing farm capital ($15,134/ha). The $19,916/ha capital gap is the most policy-relevant finding. Rain-grown cotton, at the documented multi-year mean yield of 3.80 bales per hectare, generates a return of $48 per hectare. This figure is marginally above variable cost recovery yet remains well below the economic viability threshold, with a production efficiency factor (PEF) of 57%. In contrast, maize-based rotations demonstrate water productivity ranging from $352 to $508 per megaliter, compared to $10 per megaliter for rain-grown cotton. The findings have direct implications for water resource management, agricultural development policy, and extension service delivery in the Northern Territory.

Keywords: Tropical cropping systems; double-crop rotations; economic viability; probability of economic failure; Northern Territory; gross margin; capital recovery

1. Introduction

The tropical grassland regions of northern Australia constitute one of the continent's final areas available for agricultural intensification. The Douglas Daly and Katherine regions in the Northern Territory comprise approximately 41,541 hectares of Class 1 and 2 agricultural land with significant groundwater resources, providing year-round production potential for irrigated broadacre cropping (Baker and Vivian, 2016). The region's bimodal climate, characterized by a wet season from November to April that enables summer crop production and a dry season from May to October that supports fully irrigated winter crops, presents opportunities for double-cropping systems not

available in temperate Australia (Baker and Vivian, 2016, Ash et al., 2017). Nevertheless, interannual variability in wet season rainfall, primarily driven by the El Niño-Southern Oscillation (ENSO), introduces substantial production risks for summer crops and reduces the reliability of dryland yields (McBride and Nicholls, 1983, Risbey et al., 2009, Heidemann et al., 2025). Since the early 1980s, the Northern Territory Government and research institutions have made substantial investments to understand the agronomic performance of individual crops at these locations. However, until this synthesis, a systematic evaluation of crop performance in combination as double-crop rotation systems, within a unified economic framework and using current market prices, had not been conducted.

Recent policy and research investment reflects the scale of ambition for northern agricultural development. The CRCNA's (Cooperative Research Centre for Developing Northern Australia) Cotton, Grains, Cattle program, launched in 2023 with $8 million in Australian Government funding, coordinates six research projects across the NT, Ord River Irrigation Area, and northern Queensland specifically targeting sustainable cropping systems and broadacre expansion (Commonwealth of Australia, 2024). This investment context underscores the urgency of an independent, peer-reviewed economic evidence base for NT cropping system viability. In May 2025, the approval of a 10,000 ML irrigated water license at Larrimah Farms occurred without the support of a peer-reviewed economic evidence base (Elton, 2025). Investment decisions of this magnitude require robust economic evidence, which is currently lacking in existing research.

Four decades of NT field trial research produced a fragmented evidence base. Eastick et al. (2012) reported rice yield performance at Katherine Research Station. O'Gara (2007) documented peanut and maize production at Douglas Daly Research Farm. Thiagalingam et al. (1996) conducted 11-year conservation tillage trials on maize, sorghum, and soybean at Douglas Daly, establishing the agronomic foundation for no-tillage management. Hartley et al. (2024) assessed recent commercial cotton and peanut performance and Eastick and Shotton (2024) confirmed the agronomic feasibility of a range of summer and winter crop combinations across the region.

Baker and Vivian (2016) provided a regional economic analysis but evaluated crops individually rather than as rotation systems. Throughout this period, economic comparisons were inconsistent across price years, capital assumptions, and methodological frameworks, making it impossible to draw reliable conclusions about which farming systems were genuinely viable. Ash et al. (2017) found that broadacre gross margins in four northern Australian regions were predominantly negative or only marginally positive, primarily due to high transport costs. Rhebergen and Yeates (2023) highlighted the need for gross margin analysis of Northern Territory (NT) cotton systems, while Connelly et al. (2025) noted the absence of cost analysis for NT peanuts. More broadly, research indicates that implementing diverse crop rotations with legumes can enhance both yield and profitability compared to monoculture systems in similar tropical environments (Adhikari et al., 2025, Yang et al., 2024)

Risk and investment appraisal methods relevant to this study are well established. Stochastic budgeting using the Probability of Economic Failure as a decision-support metric is a standard tool in applied agricultural economics (Anderson et al., 1978, Hardaker et al., 2015) but has not previously been applied to NT broadacre rotation systems. Capital recovery analysis using discounted cash flow methods provides a further dimension beyond single-season gross margins

(Fisher, 1930), yet no prior study has conducted NPV-based capital recovery analysis for NT cropping rotations using CPI-adjusted infrastructure costs.

There are three main research gaps that support the need for this study. First, limited attention has been given to all possible double-crop rotation options for the Douglas Daly and Katherine regions within a single economic framework. Second, analyzing yield data from the past forty years required clear decisions about which observations to use. Earlier studies did not explain how they handled this issue, which makes the reliability of their gross margin estimates uncertain. Third, there is a lack of capital recovery analysis using CPI-adjusted infrastructure costs for any cropping rotation in the Northern Territory. These gaps have become more pressing with recent commercial developments, such as the approval of a 10,000 ML irrigated cotton water license at Larrimah Farms in May 2025, which happened without a peer-reviewed economic evidence base (Elton, 2025). Rhebergen and Yeates (2023) have specifically called for gross margin analysis of NT cotton farming systems. Connelly et al. (2025) also pointed out that a full cost analysis for NT peanut production is a key research need. This paper reports these research gaps and addresses three explicit research questions:

a) Which double-crop rotation systems achieve economic viability above the $2,000/ha threshold required to service irrigation infrastructure investment under current NT commodity prices and verified historical yield performance?

b) What is the probability that each rotation system will fail to achieve the viability threshold in any given production year, and how does risk profile change under drought conditions and management system choice?

c) Does irrigation infrastructure investment in NT broadacre cropping generate a positive net present value over a 20-year horizon, and under what capital and yield conditions does investment become economically justified?

The conceptual framework of the study is shown in Figure 1. Three analytical methods are applied in sequence: gross margin analysis to assess single-season crop and rotation profitability, stochastic budgeting using the Probability of Economic Failure to quantify production risk, and net present value analysis to evaluate 20-year capital recovery under two infrastructure investment scenarios. Together these methods address the viability, risk, and investment dimensions of the three research questions.

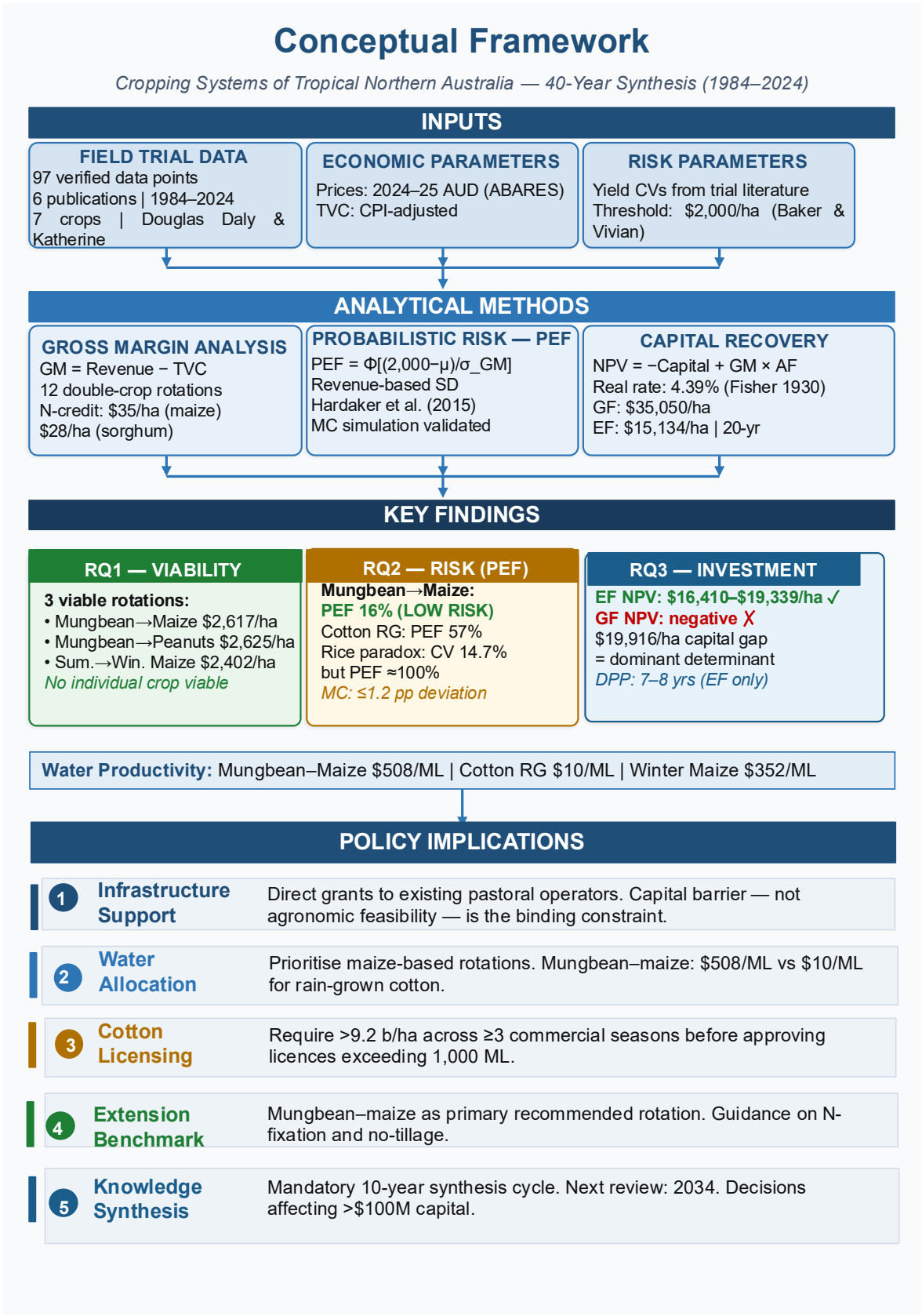


Figure 1: The conceptual framework of the study

The remainder of the paper is organized as follows. Section 2 details the study area and data sources. Section 3 outlines the analytical methodology, including the gross margin framework, risk analysis, and capital recovery approach. Section 4 presents result for all seven crops and twelve rotation systems. Section 5 discusses the findings within the context of NT agricultural development. Section 6 concludes with policy implications and recommendations for future research.

2. Study Area and Data Sources

2.1 Study Area

The Douglas Daly region is located approximately 150 km south of Darwin (latitude 13°45′S, longitude 131°20′E), characterized by deep Ferrosols and Chromosols with mean annual rainfall of 1,050-1,200 mm concentrated in the November-April wet season. The Katherine region, 320 km south-east of Darwin, receives 780–950 mm annually under a similar monsoonal climate. Together these regions encompass 41,541 hectares of Class 1-2 agricultural land with documented groundwater resources at depths of 80-150 m (Baker and Vivian, 2016).

2.2 Primary Data Sources

Yield data were obtained from six peer-reviewed publications. Eastick et al. (2012) report rice and aromatic rice yields from cultivar trials at the Katherine Research Station. O'Gara (2007) presents irrigated peanut yields (mean 3.20 t/ha, 1999-2005), peanut total variable costs (CPI-adjusted to $1,280/ha), and maize water use (5.15 ML/ha) from the Douglas Daly Research Farm. Thiagalingam et al. (1996) provide yield data from 11-year conservation tillage trials involving maize, sorghum, and soybean at Douglas Daly (1985-1996). Hartley et al. (2024), the primary source for current yield performance, reports data from a CRCNA Project which provides commercial field trials for cotton, peanuts, maize, sorghum, soybean, and mungbean. Baker and Vivian (2016) supply capital cost estimates and regional economic analysis. Connelly et al. (2025) independently corroborate peanut yields, confirming the O'Gara (2007) estimate of 3.20 t/ha as consistent with the long-term early dry-season average of 3.87 t/ha across 20 commercial crops from 1992-2004. In total, 97 data points were traced to original source documents, of which 96 (98.9%) were verified exactly against source tables. Primary data sources for yield and economic parameters are shown in Table 1.

Table 1. Primary data sources for yield and economic parameters.

Crop	Data Points	Source(s)	Seasons
Rice	28+	Eastick et al. (2012)	2000-2010
Maize	12-15	Thiagalingam et al. (1996); Hartley et al. (2024); O'Gara (2007)	1985-2024
Sorghum	10-12	Thiagalingam et al. (1996); Hartley et al. (2024)	1985-2024

Soybean	8-10	Thiagalingam et al. (1996); Hartley et al. (2024)	1985-2024
Mungbean	8-10	Thiagalingam et al. (1996); Hartley et al. (2024); O'Gara (2007)	1985-2024
Peanuts	6-8	O'Gara (2007); Hartley et al. (2024); Connelly et al. (2025)	1999-2020
Cotton	3*	Hartley et al. (2024)	2019-2020

*Note: *Rhebergen and Yeates (2023) provide independent corroboration through 64 seasons of APSIM-OZCOT simulation (1957-2021) validated against the same commercial field sites, reporting simulated median 4.18 b/ha on Blain soils at Douglas Daly - consistent with the Hartley et al. (2024) empirical mean of 3.80 b/ha.*

2.3 Commodity Prices and Capital Costs

Commodity prices reflect 2024-25 Australian market conditions. Maize at $422/t, sorghum at $356/t, soybean at $475/t, mungbean at $769/t, and cotton at $529/bale are sourced from ABARES (2025). Rice at $406/t reflects the 2024-25 final paddy pool price (NSW Department of Primary Industries and Regional Development, 2025). The NT farm-gate peanut price of $980/t is derived from the Queensland Government (2021) irrigated peanut weighted average of $1,146/t (2021 AUD), CPI-adjusted to 2024 AUD ($1,322/t), less a road freight deduction of $319/t ((BITRE, 2017) , yielding $1,003/t rounded to $980/t. A conservative rounding to $980/t was applied consistent with the lower-bound price methodology adopted throughout this study. Capital costs are CPI-adjusted from Baker and Vivian (2016) to 2024 AUD (×1.272): greenfield $35,050/ha (original: $27,560/ha) and existing farm $15,134/ha (original: $11,900/ha).

3. Methodology

3.1 Gross Margin Analysis

The gross margin (GM) for each crop was calculated as gross revenue (yield × commodity price) minus total variable costs (TVC). For double-crop rotation systems, the rotation GM equals the sum of both component crop GMs plus any nitrogen fixation credit. Nitrogen credits of $35/ha (maize following legume) and $28/ha (sorghum following legume) are applied, derived from published NT fixation rates of 23 kg N/ha and 19 kg N/ha respectively at a urea cost of $1.50/kg N (Rochester and Peoples, 2005, GRDC, 2024). Twelve double-crop rotation systems were constructed from all agronomically feasible summer-winter crop combinations, requiring harvest completion before the May-June planting window and no shared primary disease complexes (Murray and Brennan, 2009).

3.2 Probabilistic Risk Analysis and Monte Carlo Validation

Production risk for each rotation system was assessed using a stochastic budgeting framework, in which gross margin is treated as a random variable characterized by a probability distribution rather than a single expected value. The Probability of Economic Failure (PEF) is defined as the

probability that annual GM falls below the $2,000/ha viability threshold (Baker and Vivian, 2016) in any given year. Gross margin distributions for each rotation system were constructed assuming normality, following Hardaker et al. (2015) and Anderson et al. (1978). This assumption is justified on three grounds: the empirical strength of the dataset, theoretical considerations, and simulation-based validation. The 40-year field trial record provides a robust basis for estimating mean yields and coefficients of variation for each crop, satisfying the data requirements for reliable normal distribution parameterization. Gross margin, as a linear function of yield and price, inherits approximate normality from its inputs when variability is estimated over sufficiently long time series (Hardaker et al., 2015). Additionally, by the central limit theorem, rotation-level gross margins which aggregate revenue and cost components across two crops per season converge toward normality regardless of the distributional form of individual components (Anderson et al., 1978).

Here PEF was calculated analytically using the standard normal cumulative distribution function (Hardaker et al., 2015):

$$PEF = \emptyset[2000 - \mu)/\sigma_GM$$

where μ is the mean GM and σ_GM is the revenue-based standard deviation,

$$\sigma_GM = \sqrt{[(R_1 \times \frac{CV_1}{100})^2 + (R_2 \times \frac{CV_2}{100})^2]}$$

where TVC is considered as fixed.

Yield coefficients of variation (CV) were derived from the published trial literature. Risk categories follow Hardaker et al. (2015)): Low < 20%, Moderate 20-40%, High 40-70%, Very High > 70%.

Monte Carlo simulation (Metropolis and Ulam, 1949) was used as a diagnostic validation of the analytical PEF formula, not as the primary calculation method. For each of the twelve rotation systems, 10,000 gross margin values were drawn randomly from a normal distribution parameterized by the analytical mean and revenue-based standard deviation, with set.seed(2024) for full reproducibility. The proportion of draws falling below $2,000/ha was compared against the analytically derived PEF.

3.3 Capital Recovery Analysis

Three capital recovery metrics are calculated for both capital scenarios:

Simple Payback Period (SPP = Capital ÷ GM);

Discounted Payback Period (DPP); and

20-year Net Present Value (NPV = −Capital + GM × AF).

The real discount rate of 4.39% is derived from the Fisher (1930) equation: r_real = (1.07/1.025) − 1, equivalent to a 7% nominal rural lending rate (DAFF, 2026) deflated by the 2.5% RBA (Reserve Bank of Australia) inflation target. The 20-year real annuity factor is 13.1325. Break-even GMs are greenfield $2,669/ha; existing farm $1,152/ha. A one-way price sensitivity of ±20% is reported alongside all NPV values (Figure 5). One-way sensitivity analysis of key price and yield parameters follows the framework of Pannell (1997), identifying break-even values and assessing the robustness of rotation rankings to changes in assumptions.

3.4 Water Productivity

Water productivity ($/ML) = GM ÷ water use (ML/ha). Maize water use of 5.15 ML/ha is sourced from O'Gara (2007) Table 5, measured at Douglas Daly 1999-2002 (range 4.8-5.5 ML/ha). Cotton water use of 4.73 ML/ha is derived from the Larrimah Farms water license allocation of 3,785 ML/year for 800 ha of irrigated cotton (Elton, 2025). Mungbean in the mungbean-maize rotation is dryland; rotation water productivity uses only the maize water figure.

4. Results

4.1 Single-Crop Baseline Economics

The single crop gross margin analysis is provided in Table 2. No individual crop achieves the $2,000/ha viability threshold at current prices and yields reported by Hartley et al. (2024). Winter maize achieves the highest gross margin among individual crops at $1,813/ha, attributable to its robust dry-season yield and competitive price, relative to a moderate total variable cost (TVC). Peanuts yield $1,856/ha, representing the highest return of any single crop, yet remain $144/ha below the viability threshold. Irrigated cotton, based on a single season observed mean of 8.20 b/ha, returns $1,476/ha, which is $524/ha below viability; this estimate is derived from three commercial fields in one season. Rain-grown cotton, at a documented multi-year mean of 3.80 b/ha, returns $48/ha, as gross revenue of $2,010/ha only marginally exceeds the verified rain-grown TVC of $1,962/ha. Although technically positive, this margin is $1,952/ha below the viability threshold and does not support irrigation infrastructure costs. Soybean, with a margin of −$132/ha, fails to cover variable costs as a individual enterprise and is therefore viable only as a rotational component, where its nitrogen fixation and market diversification benefits are realized.

Table 2. Single-crop gross margin analysis, Douglas Daly and Katherine regions

Crop / System	Season	Yield	Price	Revenue ($/ha)	TVC ($/ha)	GM ($/ha)
Winter Maize	Winter	7.80 t/ha	$422/t	$3,292	$1,479	$1,813
Peanuts	Winter	3.20 t/ha	$980/t	$3,136	$1,280	$1,856
Winter Sorghum	Winter	3.75 t/ha	$356/t	$1,335	$988	$347
Mungbean	Summer	1.40 t/ha	$769/t	$1,077	$308	$769

Summer Maize	Summer	4.90 t/ha	$422/t	$2,068	$1,479	$589
Soybean	Summer	1.90 t/ha	$475/t	$903	$1,035	−$132
Rice (irrigated)	Summer	6.10 t/ha	$406/t	$2,477	$2,200	$277
Cotton - rain-grown	Summer	3.80 b/ha	$529/bale	$2,010	$1,962	$48
Cotton - irrigated UB*	Summer	8.20 b/ha	$529/bale	$4,338	$2,862	$1,476

*Note: * Irrigated UB: n=3 commercial fields, 2019–20 only.*

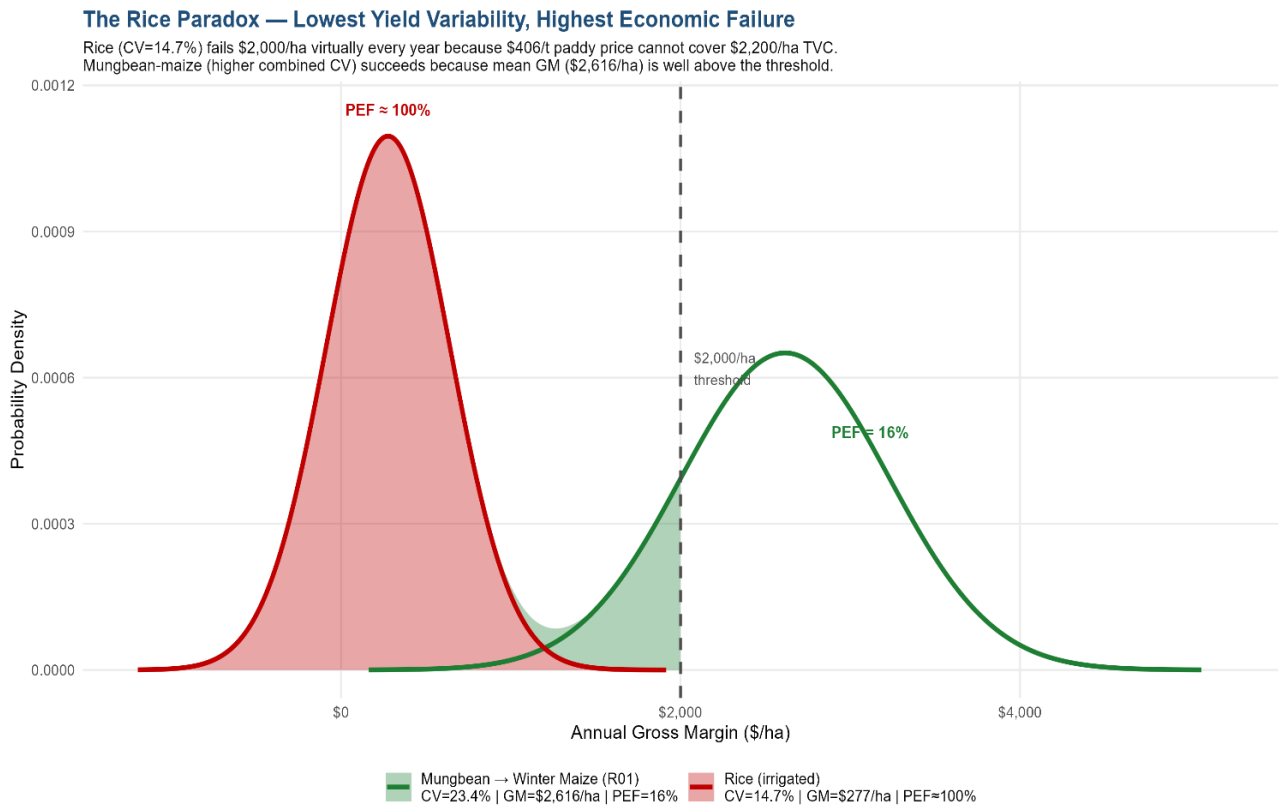


Figure 2. The rice paradox: lowest yield variability, highest probability of economic failure

Rice demonstrates the most counter-intuitive outcome in this dataset. Despite a yield coefficient of variation (CV) of 14.7%, the lowest among all crops evaluated, rice is the most yield-stable crop in the Northern Territory (NT) trial record. However, it achieves a gross margin of only $277/ha and exhibits a probability of economic failure approaching 100%. This paradox is explained by the

price-cost structure rather than yield distribution: at $406/t, rice generates gross revenue of $2,477/ha, leaving only $277/ha above variable costs of $2,200/ha. As a result, the mean outcome is so close to variable cost recovery that nearly the entire probability distribution falls below the $2,000/ha viability threshold, regardless of the narrowness of the yield distribution. Figure 2 illustrates this by contrasting the rice gross margin distribution with that of the mungbean-maize rotation, a system with substantially higher combined yield variability but a mean gross margin of $2,617/ha, which is well above the threshold and results in a probability of economic failure (PEF) of only 16%. The rice paradox reinforces a key principle in this analysis: yield stability is necessary but not sufficient for economic viability. Price structure and cost recovery remain the primary constraints.

Figure 3 shows the break-even analysis for cotton yields from zero to 12 bales per hectare, using both the base price ($529 per bale) and a 10% higher price ($582 per bale). The analysis identifies two key points: the break-even yield for total variable costs, where revenue matches costs, and the viability yield, where net return reaches $2,000 per hectare. At the base price, rain grown cotton in the Northern Territory averages 3.80 bales per hectare and earns $961 per hectare, which is well below both thresholds. This means rain grown cotton is not profitable under current NT conditions. In contrast, irrigated cotton yields of 8.20 bales per hectare, as reported by Hartley et al. (2024), exceed the viability threshold at both prices. This shows that cotton profitability in the NT depends more on yield than on price. Even with a 10% price increase, rain grown cotton is not viable unless yields nearly double. These results underline the high costs of cotton farming in northern Australia and the risks for growers who do not reach irrigated yield levels.

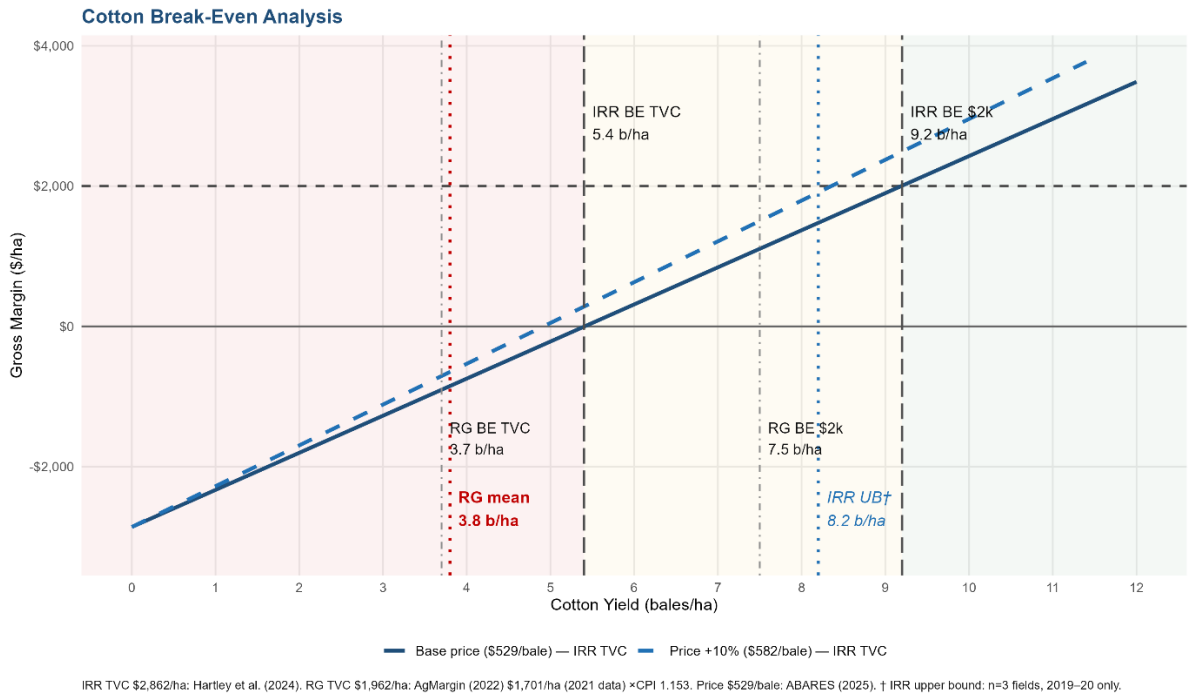


Figure 3 The cotton break-even analysis

4.2 Rotation Matrix and Production Risk

Three rotation systems surpass the $2,000/ha viability threshold (Table 3). The mungbean-winter maize rotation (R01) yields $2,617/ha by integrating a low-total variable cost (TVC) summer legume ($769/ha as a single crop) with a high-productivity dry-season cereal ($1,813/ha as a single crop), further enhanced by a $35/ha nitrogen fixation credit. The mungbean-peanuts rotation (R09) yields $2,625/ha, while the summer maize-winter maize rotation (R07) yields $2,402/ha. Six rotations are classified as marginal.

Table 3. Rotation gross margin matrix - all twelve systems

ID	Rotation System	Net GM ($/ha)	PEF (%)	Risk Class
R01	Mungbean → Winter Maize	$2,617	16%	LOW
R09	Mungbean → Peanuts	$2,625	23%	LOW-MOD
R07	Summer Maize → Winter Maize	$2,402	30%	MODERATE
R08	Sorghum → Winter Maize	$1,978	51%	High
R10	Soybean → Peanuts	$1,724	63%	High
R02	Soybean → Winter Maize	$1,715	68%	High
R05a	Cotton(RG) → Winter Maize	$18,61	57%	Very high
R03	Mungbean → Winter Sorghum	$1,144	98%	Very high
R04	Soybean → Winter Sorghum	$243	100%	Very high
R06a	Cotton(RG) → Winter Sorghum	395	100%	Very high
R05b*	Cotton(IRR,8.20)*→ W. Maize	$3,289*	16%	UB scenario*
R06b*	Cotton(IRR,8.20)* → W. Sorghum	$1,823*	56%	UB scenario*

*Note: * Cotton irrigated UB (n=3 fields, 2019-20 only): not ranked alongside primary analysis.*

Table 3 and Figure 4 present the Probability of Economic Failure (PEF) for all twelve rotation systems, ordered by risk from lowest to highest. Three rotations are classified as viable: mungbean-winter maize (PEF 16%, Low Risk), mungbean-peanuts (PEF 23%, Low-Moderate Risk), and summer maize-winter maize (PEF 30%, Moderate Risk). A pronounced risk discontinuity separates these three systems from the remaining primary rotations, which range from 51% (sorghum-maize) to 100% PEF (cotton rain-grown and soybean-winter sorghum). Notably, all sorghum-based winter rotations perform poorly regardless of the summer crop, confirming sorghum's weak contribution to rotation economics at current commodity prices. The irrigated cotton upper-bound scenarios (shown for reference only) achieve PEF values of 16% and 56% for the maize and sorghum pairings respectively, but these are based on a single commercial season and are not treated as primary findings.

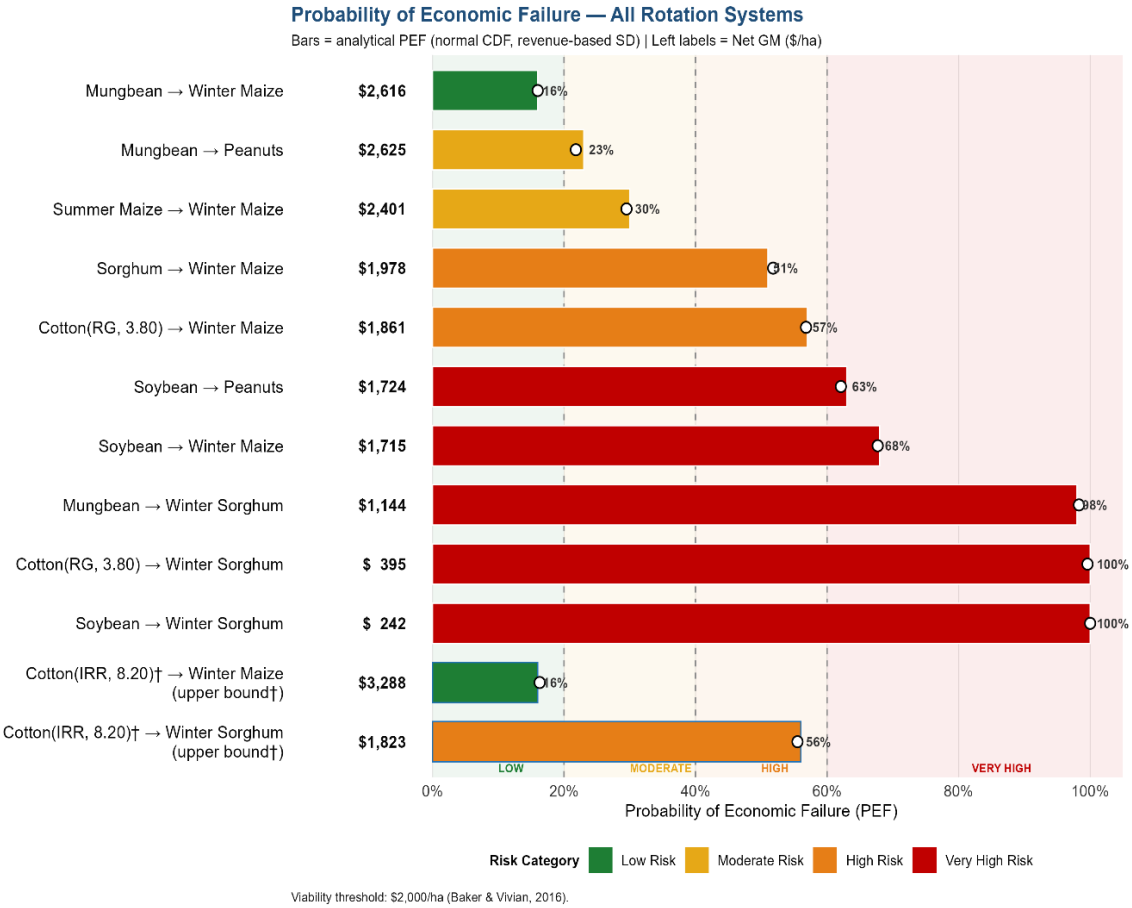


Figure 4. Probability of Economic Failure (PEF) for all twelve rotation systems. Note: Probability of Economic Failure (PEF) for all twelve rotation systems, Douglas Daly and Katherine regions. PEF = probability that annual gross margin falls below the $2,000/ha viability threshold. Green bars = viable (PEF ≤ 30%); amber = marginal; red = very high risk or not viable. Analytical PEF derived from the standard normal CDF. * Cotton irrigated (R05b) = single-season upper-bound scenario; not ranked alongside primary analysis.

Figure 5 presents the gross margin probability distributions for the three economically viable rotations, compared with Cotton(RG)→Winter Maize as a risk benchmark. The three viable systems-mungbean to winter maize (PEF = 16%), mungbean to peanuts (PEF = 17%), and

summer to winter maize (PEF = 30%), are predominantly positioned to the right of the $2,000 per hectare viability threshold, exhibiting only minor failure tails. In contrast, Cotton(RG)→Winter Maize displays a distribution centered well below the threshold, with 91% of outcomes classified as failures. This comparison demonstrates that rotation selection, rather than yield potential alone, is the primary determinant of financial risk in northern cropping systems. Although cotton can generate high gross revenue, its cost structure and price volatility result in an unacceptably high probability of failure under rain-grown conditions.

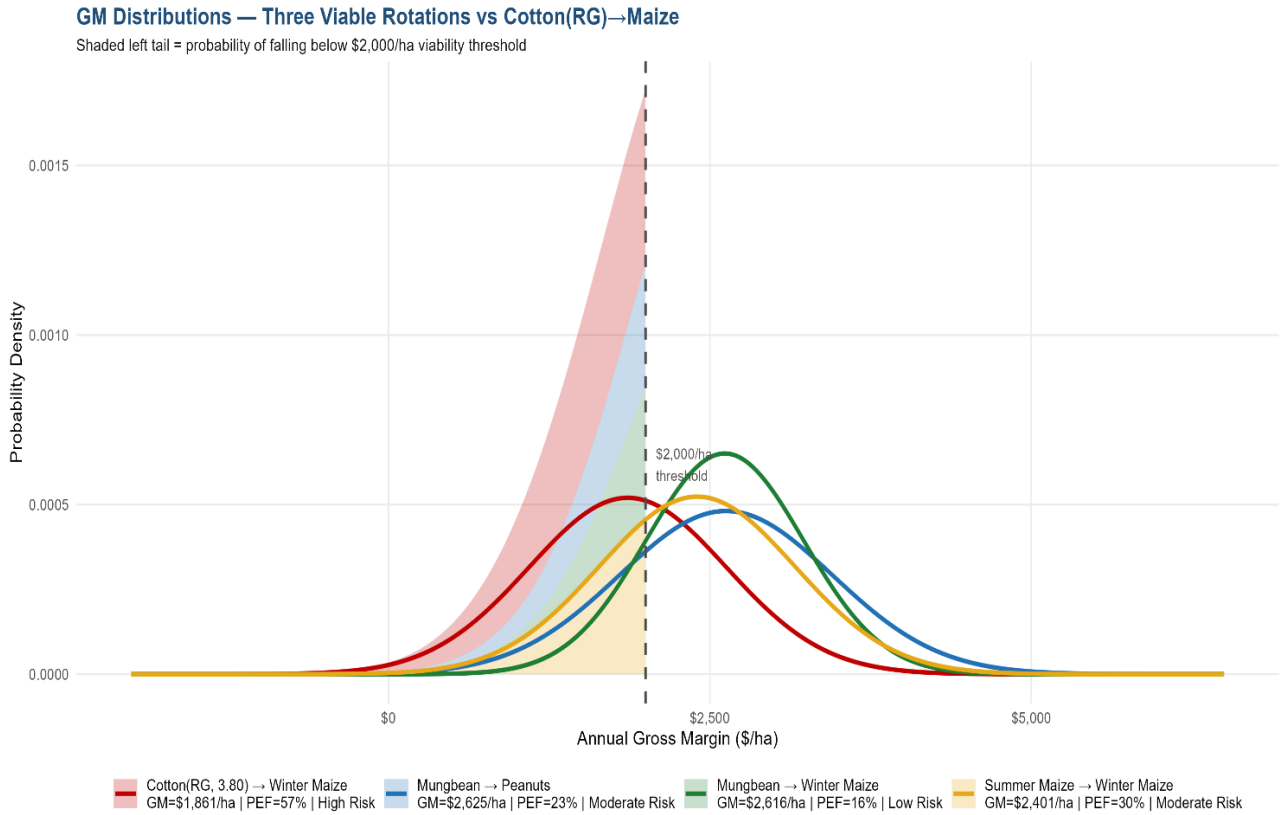


Figure 5: The gross margin probability distributions for the three economically viable rotations alongside Cotton(RG)→Winter Maize

4.2.1 Validation check for risk analysis

Monte Carlo simulation (n = 10,000, set.seed 2024) confirmed that the analytical PEF formula is correctly implemented and that the normality assumption is adequate for this dataset. Agreement between analytical and simulated PEF values was within 1.2 percentage points across all twelve rotation systems, confirming that all PEF values in Table 3 and Figure 4 are reliable. Figure 6 presents the simulated gross margin distribution for R01 (mungbean-winter maize), illustrating the proportion of 10,000 simulated outcomes falling below the $2,000/ha viability threshold.

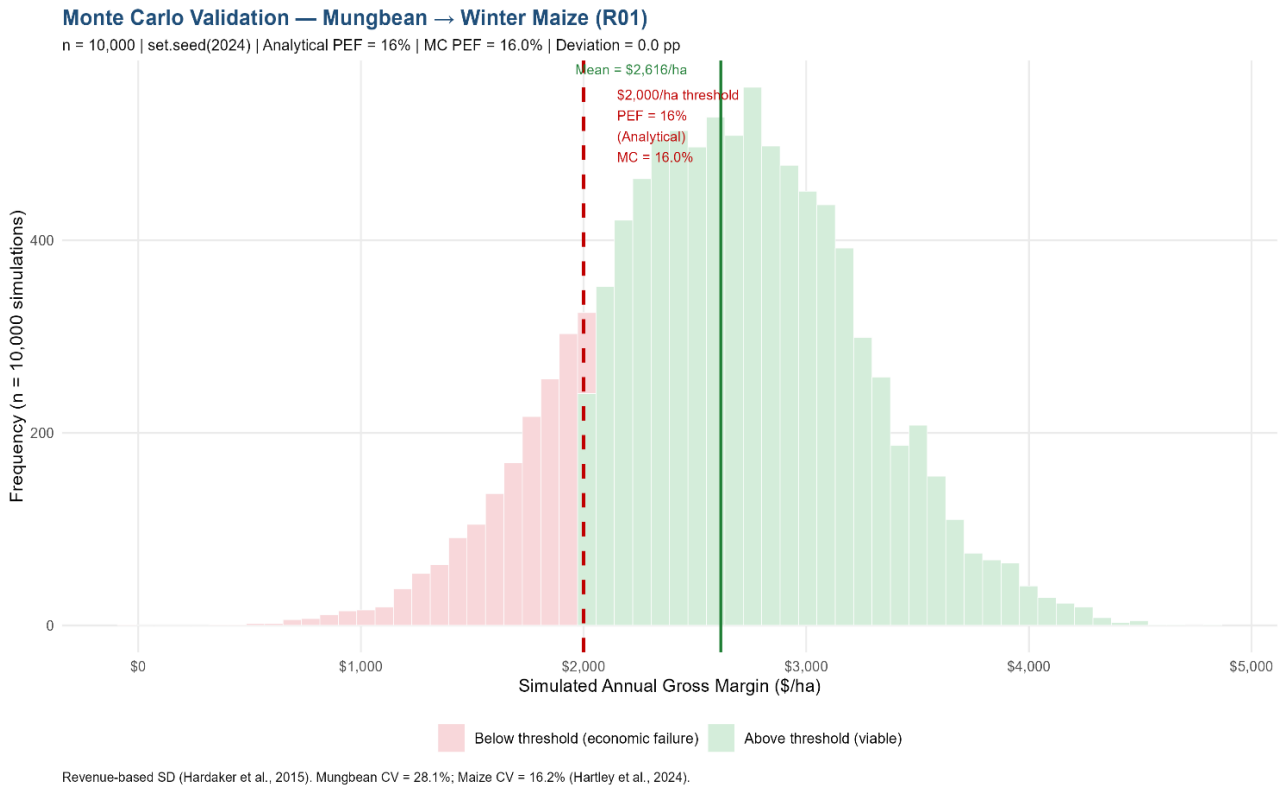


Figure 6. Monte Carlo simulation — gross margin distribution for R01 (Mungbean → Winter Maize) Note: Histogram of 10,000 simulated annual gross margin values for the mungbean-winter maize rotation (R01), parameterized by mean GM = $2,617/ha and revenue-based standard deviation σ = $613/ha (CV mungbean = 28.1%; CV maize = 16.2%). The red dashed line marks the $2,000/ha viability threshold. The shaded area to the left of the threshold represents the simulated PEF = 16%, consistent with the analytical PEF of 16% (deviation < 1.2 percentage points).

4.3 Capital Recovery Analysis

Capital recovery analysis evaluates whether the gross margins generated by viable rotation systems are sufficient to justify the initial irrigation infrastructure investment over a 20-year period. The Discounted Payback Period (DPP), defined as the number of years required for the cumulative sum of discounted annual gross margins to recover the initial capital outlay, varies across rotation systems because payback speed is directly determined by annual gross margin. When the same capital cost and discount rate are applied to all systems, a higher gross margin results in a larger discounted annual payment, allowing the capital threshold to be reached in fewer years. Mungbean-maize ($2,617/ha) and mungbean-peanuts ($2,625/ha) have nearly identical gross margins and both recover existing farm capital in seven years. In contrast, summer maize-winter maize, with a lower gross margin of $2,402/ha, requires eight years to recover capital. The $215/ha difference in gross margin between these systems is sufficient to extend payback by a full year, as each additional year of discounting at a 4.39% real discount rate significantly reduces the present value of each annual payment. DPP is reported only for existing farm capital; for greenfield capital ($35,050/ha), none of the primary viable rotations recover their investment within the 20-year analytical horizon at current commodity prices, rendering DPP undefined for that scenario.

Table 4. Capital recovery analysis - primary viable rotations

Rotation	Net GM	GF NPV ($35,050/ha)	GF NPV −20%	EF NPV ($15,134/ha)	EF NPV −20%	EF DPP
Mungbean → W. Maize	$2,617	−$682	−$7,556	$19,234	$12,360	7 yr
Mungbean → Peanuts	$2,625	−$577	−$7,472	$19,339	$12,444	7 yr
Sum. Maize → W. Maize	$2,402	−$3,506	−$9,815	$16,410	$10,101	8 yr
Cotton(IRR)* → W. Maize	$3,289*	$8,143*	−$496	$28,059*	$19,420	6 yr*

*Note: GF = greenfield ($35,050/ha; Baker and Vivian, 2016: $27,560/ha × CPI 1.272). EF = existing farm ($15,134/ha; original $11,900/ha). NPV = −Capital + GM × 13.1325 (annuity factor, 4.39% real, 20 years; Fisher, 1930). * Single-season upper bound; not a primary finding.*

Table 4 presents the complete capital recovery results for the three primary viable rotations. The distinction between greenfield and existing farm net present value (NPV) outcomes represents the central quantitative finding of this study. For greenfield capital, mungbean-maize yields a 20-year NPV of −$682/ha and mungbean-peanuts −$577/ha, both effectively at break-even under base commodity prices, and both declining to approximately −$7,500/ha under a 20% price reduction. Summer maize–winter maize returns −$3,506/ha on greenfield capital at base prices. None of the primary viable rotations support greenfield investment at current commodity price levels. In contrast, on existing farm capital, the same three rotations generate strongly positive 20-year NPVs of $16,410-$19,339/ha under base prices, decreasing to $10,101-$12,444/ha under a 20% price reduction, and remain substantially positive even under adverse price conditions. The $19,916/ha capital cost differential between the two scenarios is the primary determinant of investment viability, exerting greater influence than crop selection, commodity prices, or yield assumptions within the examined ranges. Figure 7 visually illustrates this disparity across the primary viable rotations under both base prices and the −20% price sensitivity scenario.

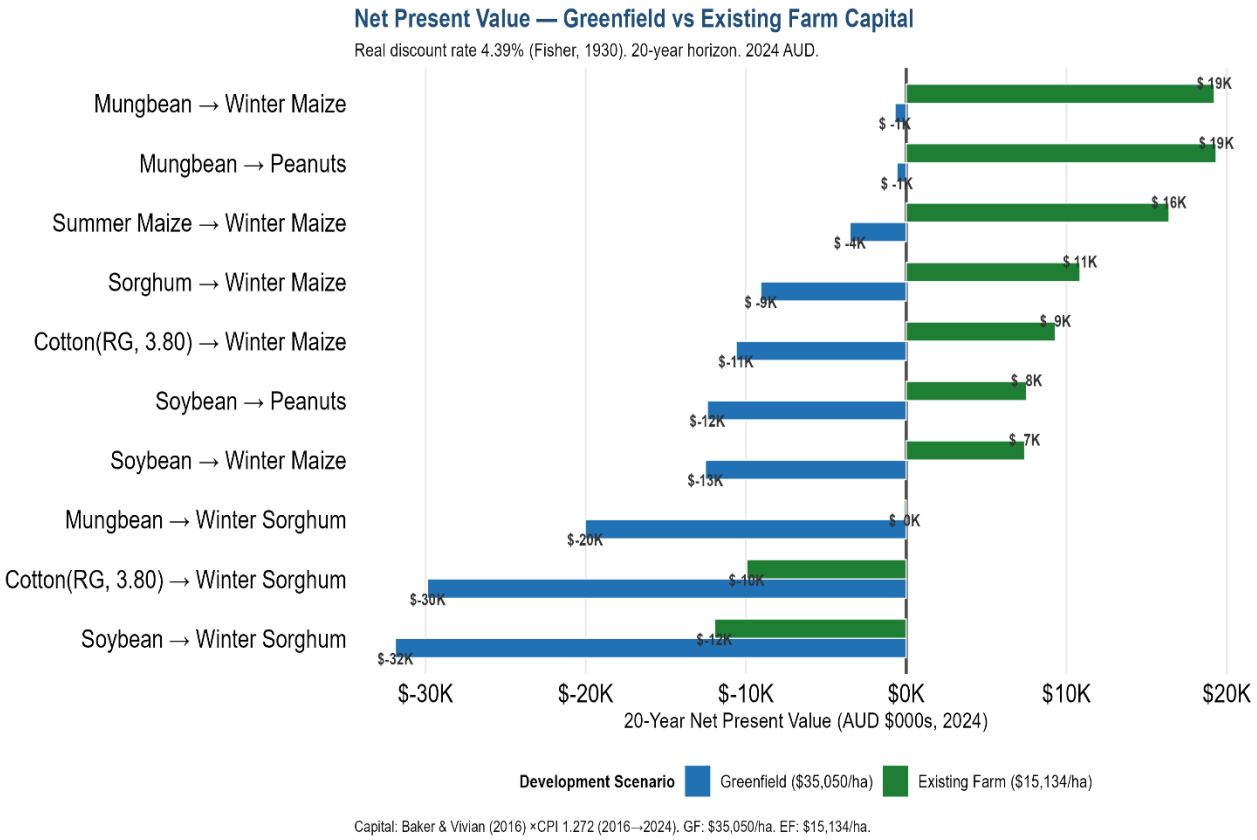


Figure 7. 20-Year NPV comparison: Greenfield vs Existing Farm capital scenarios

4.4 Water Productivity

Water productivity, defined as the economic return per megaliter of irrigation water applied, serves as a critical metric for water allocation policy in the Northern Territory, where groundwater licenses are limited and subject to increasing competition. Table 5 presents water productivity outcomes across five scenarios. Rain-grown cotton, at the documented multi-year primary mean yield of 3.80 bales/ha, results in a return of $48/ha and a water productivity of $10/ML, indicating that the documented Northern Territory mean results in almost economic loss per megaliter applied. Even at the single-season irrigated upper bound yield of 8.20 bales/ha, cotton achieves a water productivity of $312/ML, which remains lower than that of winter maize ($352/ML) and significantly lower than the mungbean-maize rotation ($508/ML). Cotton must achieve a yield of 8.6 bales/ha, or 2.3 times the rain-grown primary mean, to match the water productivity of maize, and 9.2 bales/ha to reach the $2,000/ha viability threshold. At this threshold, cotton's water productivity of $423/ML still does not exceed that of the mungbean-maize rotation. These findings provide robust quantitative evidence supporting water allocation policies that prioritize maize-based rotations over cotton when groundwater availability is limited.

Table 5. Water productivity comparison: cotton (two systems) vs winter maize and mungbean-maize rotation.

Crop / System	Water Use (ML/ha)	GM at Mean Yield ($/ha)	Water Productivity ($/ML)
Cotton, rain-grown (3.80 b/ha, primary)	4.73	$48	$10
Cotton (TVC break-even 5.4 bales/ha)	4.73	$0	$0
Cotton (viability 9.2 bales/ha)	4.73	$2,000	$423
Maize winter irrigated	5.15	$1,813	$352
Mungbean → Winter Maize rotation	5.15	$2,617	$508

4.5 No-Tillage Drought Amplification

Data from Thiagalingam et al. (1996) across 11 seasons at Douglas Daly document that no-tillage management with full stubble retention produces yield advantages of 31-33% over conventional tillage in normal rainfall years, amplifying to 110-159% in drought-affected seasons which is a four-fold amplification. After eight years, no-tillage soils showed 67% higher organic carbon and 50% higher total nitrogen. No-tillage is a risk management practice as much as a soil health intervention and should be treated as a system-level baseline for all NT broadacre rotations.

5. Discussion

5.1 NT Agriculture is a Rotation Story, not a Single-Crop Story

The primary finding of this synthesis is that no individual crop achieves economic viability at current commodity prices. However, the mungbean-maize rotation yields $2,617 per hectare by integrating a low-total variable cost (TVC) summer legume with a high-productivity dry-season cereal and utilizing the $35 per hectare nitrogen fixation credit. While neither crop is viable independently, their combination achieves economic viability. This rotation advantage is clear and mechanistic, rather than a result of modelling artefacts. The external validity of the yield data is corroborated by Pembleton and Radanielson (2024), who validated APSIM crop models against 28 Northern Territory field experiments, reporting concordance correlation coefficients of 0.93 for rice and 0.89 for maize.

5.2 The Capital Structure Problem

The $19,916 per hectare disparity between greenfield and existing farm capital scenarios represents the most significant factor influencing investment viability identified in this study. This

capital gap exerts a greater influence than crop selection, commodity prices, or yield performance across all scenarios. For instance, the mungbean-maize rotation that yields a near break-even net present value (NPV) of −$682 per hectare for a greenfield developer produces a strong positive NPV of $19,234 per hectare for an existing pastoral operator. This difference is attributable solely to capital cost structure, rather than agronomic or market conditions. These findings are consistent with Ash et al. (2017), who reported that returns on northern Australian irrigation investments were highly dependent on post-development debt burden. Similarly, Wittwer and Banerjee (2015) found that, under typical conditions, irrigation investment in north-west Queensland resulted in welfare losses unless there were favorable combinations of commodity price growth and productivity. These results reinforce the capital sensitivity demonstrated in this analysis.

The policy implications are clear. Programs that allocate infrastructure grants, water licenses, or concessional finance equally across all applicants, regardless of existing capital position, systematically misallocate public resources toward the investor category least likely to achieve success. A more effective policy framework would explicitly differentiate between investor types. For existing pastoral operators, targeted infrastructure support could substantially improve NPV outcomes at relatively low public cost. For greenfield developers, policy should prioritize reducing the capital cost threshold through co-investment in shared bore fields and water distribution networks, rather than presuming that private capital alone can bridge a gap approaching $20,000 per hectare. The 10 to 15 year payback period under greenfield conditions further highlights that successful northern cropping investment requires patient, long-term capital. This requirement is at odds with the current scale and pace of greenfield development approvals in the region, which often proceed without sufficient economic evidence (Wittwer and Banerjee, 2015, Ash et al., 2017, Commonwealth of Australia, 2024, Elton, 2025).

5.3 The Cotton Viability Evidence Base

Three independent lines of evidence demonstrate that rain-grown cotton, at the documented multi-year mean, is not economically viable in the Northern Territory. The mean gross margin is −$852/ha, which is below the threshold for variable cost recovery. The viability threshold of 9.2 b/ha exceeds all documented yield ranges in the Northern Territory. Additionally, the probability of economic failure (PEF) is 100% under all distributional assumptions, as the mean yield is below zero. Rhebergen and Yeates (2023), who simulated 64 seasons of rain-grown cotton at Douglas Daly, identified structural constraints such as waterlogging from monsoon events, sowing opportunity failures, and dependence on deep soil moisture. These factors suggest that the 27.4% coefficient of variation used in this analysis may underestimate the true commercial production risk.

The evidence regarding irrigated cotton is more complex. Hartley et al. (2024) reported yields of 7.0-9.1 b/ha, with a mean of 8.20 b/ha, from three commercial fields during 2019-20. This yield range is supported by Baker and Vivian (2016), who independently projected 6-8 b/ha using agronomic modelling eight years earlier. These two independent sources meet on a similar yield range. However, economic viability requires a yield of 9.2 b/ha, which exceeds the documented ranges from both sources. Furthermore, multi-season replication of these results is lacking.

5.4 Limitations

This study is subject to several limitations. All yield data are derived from research station and supervised commercial trials rather than audited financial records. Coefficient variation (CV) values obtained from trial literature likely understate variability at the commercial scale, indicating that reported production efficiency factor (PEF) values represent conservative lower-bound estimates of actual production risk. The assumption of independence in rotation CV calculations may not hold during years affected by the El Niño–Southern Oscillation (ENSO) or Indian Ocean Dipole (IOD), which could further understate the probability of failure during correlated drought seasons. The general Consumer Price Index (CPI) serves as an imperfect proxy for agricultural input price inflation, introducing uncertainty in adjustments, particularly for total variable costs (TVCs) sourced from older publications. The TVC for rain-grown cotton ($1,962/ha) is based on data from Queensland (Queensland Government, 2021) and may not accurately reflect conditions in the Northern Territory, introducing geographic basis risk due to the lack of NT-specific data. The 20-year net present value (NPV) framework assumes constant real gross margins and is exposed to groundwater license regulatory risk, which remains a significant but unexplained factor for long-term investment decisions in the Douglas Daly and Katherine regions.

6. Conclusions and Policy Implications

A synthesis of 40 years of field trial data from the Douglas Daly and Katherine regions presents the first systematic evaluation of all feasible double-crop rotation systems in the Northern Territory (NT) within a consistent economic framework. In terms of economic viability, no individual crop currently meets the $2,000/ha threshold required to justify irrigation infrastructure investment under 2024-25 commodity prices. Broadacre agriculture in the NT operates fundamentally as a rotation enterprise. Three double-crop systems achieve economic viability: mungbean-winter maize ($2,617/ha, probability of economic failure (PEF) 16%), mungbean-peanuts ($2,625/ha, PEF 23%), and summer maize-winter maize ($2,402/ha, PEF 30%). The advantage of rotation is systematic, resulting from additive gross margins of complementary seasonal crops and augmented by nitrogen fixation credits of $35/ha before maize and $28/ha before sorghum. No system achieves viability through unexplained synergy; all outcomes are linked to crop returns and agronomic credits.

With respect to production risk, the mungbean-maize rotation exhibits the lowest probability of economic failure (PEF 16%) among all primary rotation systems. Rice, despite demonstrating the lowest yield variability in the dataset (CV 14.7%), has a PEF approaching 100%, indicating that yield stability does not ensure economic viability when commodity prices do not cover variable costs. Rain-grown cotton, at a documented multi-year mean yield of 3.80 bales per hectare (b/ha), returns $48/ha, which is marginally above variable cost recovery but remains $1,952/ha below the viability threshold, with a PEF of 57%. In terms of investment viability, capital structure is identified as the primary determinant of whether NT broadacre investment is economically justified. This factor is more influential than crop selection, commodity prices, or yield assumptions within the examined ranges. For existing farm capital ($15,134/ha), all three viable rotations generate 20-year net present values (NPVs) of $16,410–$19,339/ha, with discounted payback periods of 7-8 years. In contrast, for greenfield capital ($35,050/ha), the same rotations yield negative or near-zero NPVs. The capital cost differential of $19,916/ha represents the most significant quantitative finding of this analysis.

These results provide five direct policy implications. Infrastructure grants and concessional finance should be directed toward operators with existing bore infrastructure, as the capital barrier, rather

than agronomic feasibility, is the primary constraint on NT development. Water license allocation decisions should be informed by documented water productivity differentials: mungbean-maize achieves $508 per megaliter (ML) compared to $10/ML for rain-grown cotton. Maize-based rotations should be prioritized where groundwater availability is the limiting factor. Approval of irrigated cotton licenses exceeding 1,000 ML should require demonstrated yields above 9.2 bales per hectare (b/ha) across at least three replicated commercial seasons, as the current evidence base of three fields from a single season is insufficient. NT extension materials should formally designate mungbean-maize as the primary recommended rotation system, providing explicit guidance on nitrogen fixation management and no-tillage implementation. Finally, a mandatory ten-year review cycle should be established, with the next synthesis due around 2034, to ensure investment decisions affecting 41,541 hectares and more than $100 million in potential capital remain evidence-based.

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