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Water resource assessment for the Southern Gulf catchments

A report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid

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Important disclaimer

CSIRO Southern Gulf Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory (NT) and Queensland governments.

The Assessment was guided by two committees:

i. The Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Southern Gulf catchments Steering Committee: Amateur Fishermen's Association of the NT; Austral Fisheries; Burketown Shire; Carpentaria Land Council Aboriginal Corporation; Health and Wellbeing Queensland; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Prawn Fisheries; Queensland Department of Agriculture and Fisheries; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Regional Development, Manufacturing and Water; Southern Gulf NRM

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

This report was reviewed by Mr Mike Grundy (Independent consultant). Individual chapters were reviewed by Dr Peter Wilson, CSIRO (Chapter 2); Dr Andrew Hoskins, CSIRO (Chapter 3); Dr Brendan Malone, CSIRO (Chapter 4); Dr James Bennett, CSIRO (Chapter 5); Dr Nikki Dumbrell, CSIRO (Chapter 6); Mr Darran King, CSIRO (Chapter 7). The material in this report draws largely from the companion technical reports, which were themselves internally and externally reviewed.

For further acknowledgements, see page xxviii.

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

Saltwater Arm, a tributary of the Albert River. This view typifies the tidal rivers and estuaries along the southern coast of the Gulf of Carpentaria. Source: Shutterstock

Part III Opportunities for water resource development

Chapters 4 and 5 provide information on opportunities for agriculture and aquaculture in the catchment of the Southern Gulf rivers, that is Settlement Creek, Gregory–Nicholson River and Leichhardt River, the Morning Inlet catchments and the Wellesley island groups. This information covers:

- opportunities for irrigated agriculture and aquaculture (Chapter 4)
- opportunities to extract and/or store water for use (Chapter 5).

Lake Moondarra on the Leichhardt River is a favoured recreational reserve for residents and tourists of Mount Isa.

Photo: CSIRO – Nathan Dyer

4 Opportunities for agriculture in the Southern Gulf catchments

Authors: Yvette Oliver, Seonaid Philip, Tiemen Rhebergen, Ian Watson, Tony Webster, Peter Zund, Simon Irvin

Chapter 4 presents information about the opportunities for irrigated agriculture and aquaculture in the catchment of the Southern Gulf rivers, that is Settlement Creek, Gregory–Nicholson River and Leichhardt River, the Morning Inlet catchments and the Wellesley island groups[1], describing:

- land suitability for a range of crop group × season × irrigation type combinations and for aquaculture, including key soil-related management considerations
- cropping and other agricultural opportunities, including crop yields and water use
- gross margins at the farm scale
- prospects for integration of forages and crops into existing beef enterprises
- aquaculture opportunities.

The key components and concepts of Chapter 4 are shown in Figure 4-1.

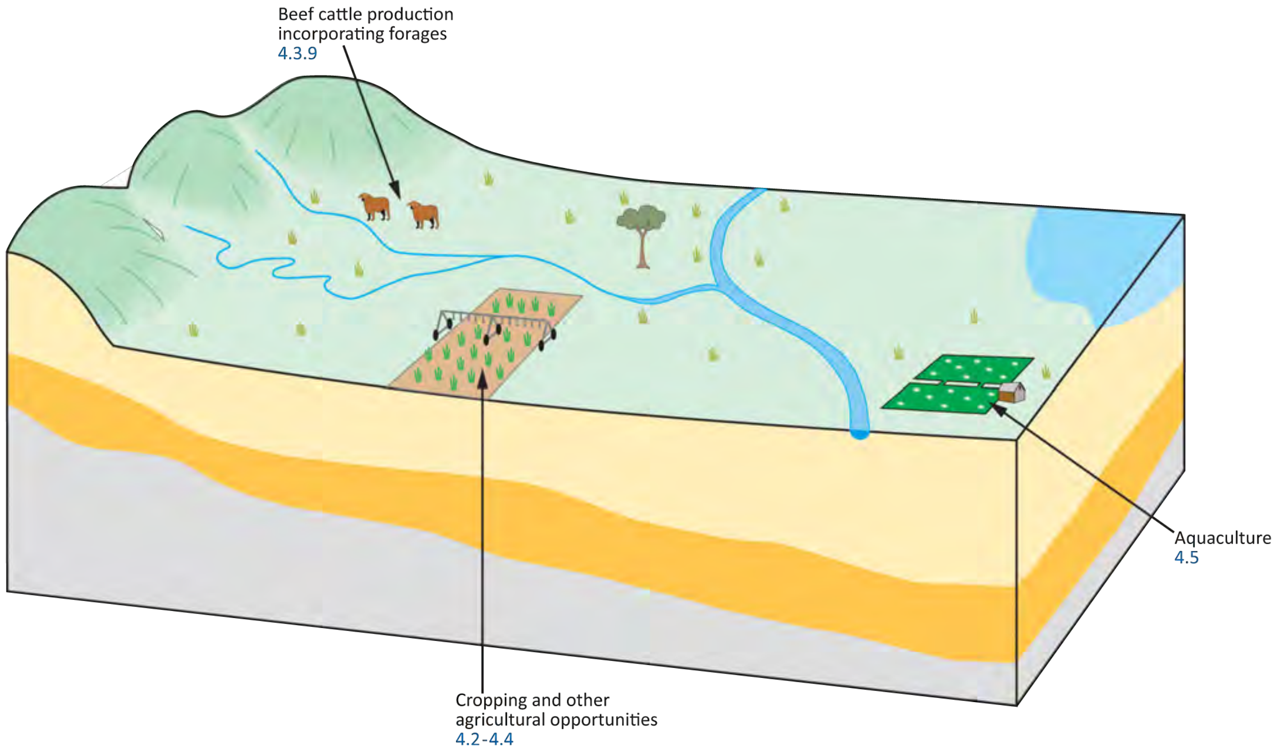

Figure 4-1 Schematic of agriculture and aquaculture enterprises as well as crop and/or forage integration with existing beef enterprises to be considered in the establishment of a greenfield irrigation development

[1] Only those islands greater than 1000 ha are mapped

4.1 Summary

This chapter provides information on land suitability and the potential for agriculture and aquaculture in the Southern Gulf catchments. A mixture of field surveys and desktop analysis were used to generate the results presented in this chapter. For example, the land suitability results draw on extensive field visits (to describe, collect and analyse soils) and are integrated with state-of-the-art digital soil mapping. Many of the results are expressed in terms of potential. The area of land suitable for cropping or aquaculture, for example, is estimated by considering the set of relevant soil and landscape biophysical attributes at each location and determining the most limiting attribute among them. It does not include water availability; cyclone or flood risk; legislative, regulatory or tenure considerations; or ecological, social or economic drivers that will inevitably constrain the actual area of land that is developed. Crops, forages and cropping systems results are based on data analysis and simulation models, and assume good agronomic practices producing optimum yields given the soil and climate attributes in the catchments. Likewise, aquaculture is assessed in terms of potential, using a combination of land suitability and the productive capacity of a range of aquaculture species. Information is presented in a manner to enable the comparison of a variety of agricultural and aquaculture options.

The results from individual components (land suitability, agriculture, aquaculture) are integrated to provide a sense of what is potentially viable in the catchments. This includes providing specific information on a wide range of crop types for agronomy, water use and land suitability for different irrigation types; analyses of economic performance, such as crop gross margins (GMs); how more-intensive mixed cropping systems might be feasible with irrigation; and analyses of what is required for different aquaculture development options to be financially viable.

4.1.1 Key findings

Any agricultural resource assessment must consider two major factors: how much soil is suitable for a particular land use and where that soil is located. Based on a sample of 14 individual combinations of crop group × season of use × irrigation type, the amount of land classified as moderately suitable with considerable limitations or better ranges from 780,000 ha (Crop Group 7, wet-season furrow) to 4.7 million ha (Crop Group 14, perennial species, spray) before constraints such as water availability, environmental and other legislation and regulations, and a range of biophysical risks are considered (crop groups are defined in Section 4.2.3). The largest contiguous areas of soil suitable for broad-scale irrigation are the grey cracking clay soils of the lowland alluvial plains (Section 2.3.2, Figure 2-5), which are well located for small-scale irrigation developments based on water harvesting. Downstream of Doomadgee there are contiguous areas of red sandy and loamy soils suitable for irrigated vegetables and in the Leichhardt catchment downstream of Kajabbi there are opportunities for irrigated horticulture on the friable levee soils, and the adjacent friable clayey soils are suitable for broadacre irrigation. The clay soils on the Barkly Tableland in the south-west are suitable for broadacre cropping and overlie areas of intermediate- to regional-scale groundwater resources.

Rainfed cropping

Despite the theoretical possibility that rainfed crops could be produced using the considerable rainfall that arrives during the wet season, in practice significant agronomic and market-related challenges to rainfed crop production have prevented its expansion. Extensive areas of heavier clay soils (soil generic group (SGG) 9) across the Armraynald Plain and Barkly Tableland store enough plant available water (PAW) that could support potential high crop yields, particularly if cropped opportunistically in wetter years. However, frequent inundation and waterlogging of clay soils means that access for farming operations could be disrupted, increasing the risk to maximum yields through compromised timing of operations. Despite these challenges, higher-value crops such as pulses or cotton show potential, especially when grown in conjunction with irrigated farming. Loamy soils have low water-holding capacity and are hardsetting, which makes consistently achieving viable rainfed yields difficult.

Irrigated cropping

Irrigation reduces crop water stress and provides greater control over scheduling of crop operations to optimise production, including the option of growing through the cooler months of the dry season.

Analyses of the performance of 19 potential irrigated cropping options in the Southern Gulf catchments indicate that achievable annual GMs could be up to about $4500/ha for broadacre crops, $8000/ha for annual row crop horticulture, $6000/ha for perennial fruit tree horticulture and $3000/ha for silviculture (plantation trees). While GMs are a key partial metric of farm performance, they should not be treated as fixed constants determined by the cropping system alone. They are a product of the farming and business management decisions, input costs and market opportunities. As such there are often niche opportunities to improve farm GMs and profitability, but these usually come at the expense of scalability. Farm financial metrics like GMs greatly amplify any fluctuations in commodity prices and input costs, so the mean GM does not accurately reflect the often substantial cashflow challenges in managing years of losses between those of windfall profits (particularly for horticulture). Crop yields and GMs presented in this chapter indicate what might be attained for each cropping option once it has achieved it's sustainable agronomic potential. It is unrealistic to assume that these levels of performance would be achieved in the early years of newly established farms, and allowance should be made for an initial period of learning (see Chapter 6).

Potential crop species that could be grown as a single crop per year were rated and ranked for their performance in the Southern Gulf catchments. Wet-season crops (planted January to early May) that are rated the most likely to be viable are cotton (*Gossypium* spp.), forages and peanuts (*Arachis hypogaea*). Dry-season crops (planted late March to August) that are rated the most likely to be viable are annual horticulture and cotton. Financial viability is determined both by crop options with the highest GMs and by associated capital and fixed costs, which are higher in more-intensive farming like horticulture. The farm-scale measures of crop performance presented in this chapter are intended to be used in conjunction with the scheme-scale analyses of financial viability in Chapter 6 (as part of an integrated multi-scale approach).

Sequential cropping systems involve planting more than one crop in the same year in the same field. These systems have the potential to significantly increase farm GMs. Annual broadacre and horticultural crops have been grown sequentially for many decades in tropical northern Australia. A wide range of sequential cropping options are potentially viable in the Southern Gulf catchments. Most suitable crop sequences include wet-season mungbean, grain sorghum or peanut with dry-season annual horticulture, wet season mungbean, peanut, soybean or grain sorghum with dry-season cotton, maize, chickpea or forage, and wet-season cotton with dry-season mungbean, sorghum or forage. Scheduling back-to-back crops could be operationally tight in the Southern Gulf catchments, particularly on clay-rich soils with poor drainage, due to limitations on paddock accessibility.

Crop selection is market driven in northern Australian regions like the Southern Gulf catchments. Rotations and crop sequences are therefore dynamic as growers develop an understanding of the benefits, trade-offs and management needs of different crop mixes and adapt to changing opportunities as commodity prices change.

Integrating forages and hay into existing beef enterprises

There are many theoretical benefits to growing irrigated forages and hay on-farm to enhance existing grazing enterprises. The use of on-farm irrigated forage and hay production would allow graziers greater options for marketing cattle: meeting market liveweight specifications for cattle at a younger age, meeting the specifications required for different markets than those typically targeted by cattle enterprises in the Southern Gulf catchments and providing cattle that meet market specification at a different time of the year. Forages and hay may also allow graziers to implement management strategies, such as early weaning or weaner feeding, which should lead to flow-on benefits throughout the herd, including increased reproductive rates. Some of these strategies are already practised within the Southern Gulf catchments but in almost all incidences are reliant on hay or other supplements purchased on the open market. By growing hay on-farm, the scale of these management interventions might be increased, at reduced net cost. Furthermore, the addition of irrigated feeds may allow graziers to increase the total number of cattle that can be sustainably carried on a property.

Analysis of two irrigated hay or two irrigated forage stand-and-graze options compared to two base enterprises (with or without purchased hay, for weaners) suggested that irrigated forages or hay increased the total income and the amount of cattle liveweight sold. GMs were highest for the two irrigated hay options. The two stand-and-graze options returned the lowest GMs. A net present value (NPV) analysis suggested that a decision to irrigate would need to assume that beef prices remain high in comparison to the mean of the previous 10 years. Irrigation enterprises of the scale required involve high capital investment and additional or novel management skills.

Aquaculture

There are considerable opportunities for aquaculture development in northern Australia given the region’s natural advantages of a climate suited to farming valuable tropical species, large areas identified as suitable for aquaculture, and political stability and proximity to large global markets. The main challenges to developing and operating modern and sustainable aquaculture enterprises are regulatory barriers, global cost competitiveness and the remoteness of much of the suitable land area. The three species with the most aquaculture potential in the Southern Gulf catchments are black tiger prawns (*Penaeus monodon*), barramundi (*Lates calcarifer*) and red claw (*Cherax quadricarinatus*).

Suitable land for lined ponds for freshwater species is widespread throughout the catchments due to the extensive distribution of favourable soil and land characteristics (flat land, non-rocky, deep soil). In contrast, options for freshwater species in earthen ponds are restricted to the impermeable alluvial clays to allow retention of water. The range for marine aquaculture is restricted to the tidal zones of the catchments and on the coastal plain within 2000 m of access to marine water.

High annual operating costs (which can exceed the initial capital costs of development) mean that managing cashflow in the establishment years is challenging, especially for products that require multi-year grow-out periods. Input costs scale with increasing productivity, so improving production efficiency (such as feed conversion rate or labour-efficient operations) is much more important than increasing yields for aquaculture to be viable in the Southern Gulf catchments. It would be essential for any new aquaculture development to refine the production system and achieve the required levels of operational efficiency (input costs per kilogram of produce) using just a few ponds before scaling the enterprise to a larger number of ponds.

4.1.2 Introduction

Aspirations to expand agricultural development in the Southern Gulf catchments are not new, and across northern Australia there have been a number of initiatives to put in place large-scale agricultural developments since World War II (Ash, 2014; Ash and Watson, 2018). Ash and Watson (2018) assessed 11 such agricultural developments, four of which continue to operate at a regionally relevant scale, namely the Ord River Irrigation Area, the lower Burdekin, the Mareeba–Dimbulah Water Supply Scheme and the Katherine mango industry. The Lakeland Downs development also continues, although it could not be categorised as regionally significant. Ash and Watson's assessment included both irrigated and rainfed developments, and considered natural, human, physical, financial and social capitals.

Key points to emerge from these analyses include the following:

- The natural environment (climate, soils, pests and diseases) makes agriculture in northern Australia challenging, but these inherent environmental factors are not generally the primary reason for a lack of success.
- The speed with which many of the developments were undertaken did not allow for a 'learning by doing' approach, leading at times to costly mistakes.
- Physical capital, in the form of on-farm infrastructure, supply chain infrastructure and crop varieties, was a significant and ongoing impediment to success. For broadacre commodities that require processing facilities, these facilities need to be within a reasonable distance of production sites and at a scale to make them viable in the long term.
- Financial plans tended to over estimate early production and returns on capital, and make overly optimistic expectations of the ability to scale up rapidly. This led to financial pressure on investors and a premature end to some developments. Furthermore, the need to have well-connected and well-paying markets was often not fully appreciated. In more remote regions, higher-value products such as fruit, vegetables and niche crops proved more successful, although high supply chain costs to both domestic and export markets remain as impediments to expansion.

- Most of the developments began in areas with no history of agricultural development, and there was no significant community of practitioners who could share experiences.
- Management, planning and finances were the most important factors in determining the ongoing viability of agricultural developments.

For developments to be successful, all factors relating to climate, soils, agronomy, pests, farm operations, management, planning, supply chains and markets need to be thought through in a comprehensive systems design. Particular attention needs to be paid to scaling up at a considered pace and being prepared for reasonable lags before achieving positive returns on investment.

This chapter addresses the following questions for the Southern Gulf catchments:

- How much land is suitable for cropping and in which suitability class?
- Is irrigated cropping economically viable?
- Which crop options perform best and how can they be implemented in viable mixed farming systems?
- Can crops and forages be economically integrated with beef enterprises?
- What aquaculture production systems might be possible?

The chapter is structured as follows:

- Section 4.2 describes how the land suitability classes are derived from the attributes provided in Chapter 2, with results given for a set of 14 combinations of individual crop group × season × irrigation type. Versatile agricultural land is described, and a qualitative evaluation of cropping is provided for a set of specific locations within the catchment.
- Section 4.3 provides detailed information on crop and forage opportunities, including irrigated crop yields, water use and GMs. Agronomic principles, such as selection of sowing time, are provided, including a cropping calendar for scheduling farm operations. The information is synthesised in an analysis of the cropping systems that could best take advantage of opportunities in the Southern Gulf catchments environments while dealing with farming challenges.
- Section 4.4 provides synopses for 11 crop and forage groups, including a focus on specific example species.
- Section 4.5 discusses the candidate species and likely production systems for aquaculture enterprises, including the prospects for integrating aquaculture with agriculture.

4.2 Land suitability assessment

4.2.1 Introduction

The term ‘suitability’ in the Assessment refers to the potential of the land for a specific land use, such as furrow-irrigated cotton. The term ‘capability’ (not used in the Assessment) refers to the potential of the land for broadly defined land uses, such as cropping or pastoral (DSITI and DNRM, 2015).

The overall suitability for a particular land use is determined by a number of environmental and soil attributes. These include, but are not limited to, climate at a given location, slope, drainage, permeability, available water capacity (AWC) of the soil, pH, soil depth, surface condition and texture. Examples of some of these attributes are provided in Section 2.3. From these attributes, a set of limitations to suitability are derived, which are then considered against each potential land use.

4.2.2 Land suitability classes

The overall suitability for a particular land use is calculated by considering the set of relevant attributes at each location and determining the most limiting attribute among them. This most limiting attribute then determines the overall land suitability classification. The classification is on a scale of 1 to 5 from ‘Suitable with negligible limitations’ (Class 1) to ‘Unsuitable with extreme limitations’ (Class 5), as shown in Table 4-1 (FAO, 1976, 1985). The companion technical report on digital soil mapping and land suitability (Thomas et al., 2024) provides a complete description of the land suitability assessment method, and the material presented in this section is taken from that report. Note that the land suitability maps and figures presented in this section do not consider flooding, risk of secondary salinisation or availability of water as discussed by Thomas et al. (2024). Consideration of these risks and others, along with further detailed soil physical, chemical and nutrient analyses, would be required to plan development at scheme, enterprise or property scale. Caution should therefore be employed when using these data and maps at fine scales.

Table 4-1 Land suitability classes based on FAO (1976, 1985) as used in the Assessment

CLASS	SUITABILITY	LIMITATIONS	DESCRIPTION
1	Suitable	Negligible	Highly productive land requiring only simple management practices to maintain economic production
2	Suitable	Minor	Land with limitations that either constrain production or require more than the simple management practices of Class 1 land to maintain economic production
3	Suitable	Moderate	Land with limitations that either further constrain production or require more than those management practices of Class 2 land to maintain economic production
4	Currently unsuitable	Severe	Currently unsuitable land due to severe limitations that preclude successful sustained use of the land for the specified land use. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology
5	Unsuitable	Extreme	The limitations are so severe that the specified land use is precluded. The benefits would not justify the inputs required to maintain production and prevent land degradation in the long term

4.2.3 Land suitability for crops, versatile agricultural land and evaluation of specific areas of interest

The suitability framework used in this Assessment aggregates individual crops into a set of 21 crop groups (Table 4-2). The groups are based on the framework used by Andrews and Burgess (2021), with some additions considered prospective based on previous CSIRO work in northern Australia (e.g. Thomas et al., 2018), including in Queensland. From this set of crop groups, land suitability has been determined for 58 land use combinations of crop group × season × irrigation type (including rainfed) (Thomas et al., 2024).

Table 4-2 Crop groups and individual land uses evaluated for irrigation (and rainfed) potential

Crop groups and land uses are based on those used by Andrews and Burgess (2021), amended for the Southern Gulf catchments with the addition of crop groups 18 to 21 based on CSIRO's previous work in northern Australia. Those used in the Northern Australia Water Resource Assessment (Thomas et al., 2018) are in boldface.

MAJOR CROP GROUP	CROP GROUP	INDIVIDUAL CROPS ASSESSED
Tree crops/horticulture (fruit)	1	Monsoonal tropical tree crops (0.5 m root zone) – **mango**, coconut, dragon fruit, Kakadu plum, bamboo, **lychee**
	2	Tropical **citrus** – lime, lemon, mandarin, pomelo, lemonade, grapefruit
Intensive horticulture (vegetables, row crops)	3	**Cucurbits** – watermelon, honeydew melon, rockmelon, pumpkin, cucumber, Asian melons, zucchini, squash
	4	Fruiting vegetable crops – Solanaceae (**capsicum**, **chilli**, eggplant, **tomato**), okra, **snake bean**, drumstick tree
	5	**Leafy vegetables** and herbs – kangkong, amaranth, Chinese cabbage, bok choy, pak choy, choy sum, basil, coriander, dill, mint, spearmint, chives, oregano, lemon grass, **asparagus**
Root crops	6	Carrot, onion, **sweet potato**, shallots, ginger, turmeric, galangal, yam bean, taro, **peanut**, **cassava**
Grain and fibre crops	7	**Cotton**, **grains** – **sorghum (grain)**, **maize**, **millet (forage)**
	8	**Rice** (lowland and upland)
Small-seeded crops	9	Hemp, **chia**, **quinoa**, **medicinal poppy**
Pulse crops (food legumes)	10	**Mungbean**, **soybean**, **chickpea**, **navy bean**, **lentil**, guar
Industrial	11	**Sugarcane**
Hay and forage (annual)	12	Annual grass hay/forages – **sorghum (forage)**, **maize (silage)**
	13	Legume hay/forages – blue pea, burgundy bean, cowpea, **lablab**, Cavalcade, forage soybean
Hay and forage (perennial)	14	Perennial grass hay/forage – **Rhodes grass**, panics
Silviculture/forestry (plantation)	15	**Indian sandalwood**
	16	**African mahogany**, *Eucalyptus* spp., *Acacia* spp.
	17	**Teak**
Intensive horticulture (vegetables, row crops)	18	**Sweet corn**

MAJOR CROP GROUP	CROP GROUP	INDIVIDUAL CROPS ASSESSED
Oilseeds	19	**Sunflower**, **sesame**
Tree crops/horticulture	20	**Banana**, **coffee**
	21	**Cashew**, **macadamia**, **papaya**

A sample of 14 of these individual land use combinations – that covers a mixture of crops, irrigation types and seasons, grown or trialled in northern Australia – is shown in Figure 4-2. Depending on land use, the amount of land classified as Class 3 or better for these sample land uses ranges from about 360,000 ha (Crop Group 10, wet-season rainfed) to 5.1 million ha (Crop Group 14 under spray irrigation). Much of this land is rated as Class 3, and so has considerable limitations, although nearly 1.7 million ha of Class 2 land is available for Crop Group 14 crops under spray irrigation and between about 340,000 ha and about 970,000 ha of Class 2 land for the other crop groups under spray or trickle irrigation. Ranges of suitability geographic distributions are shown on maps in the crop synopses in Section 4.4.

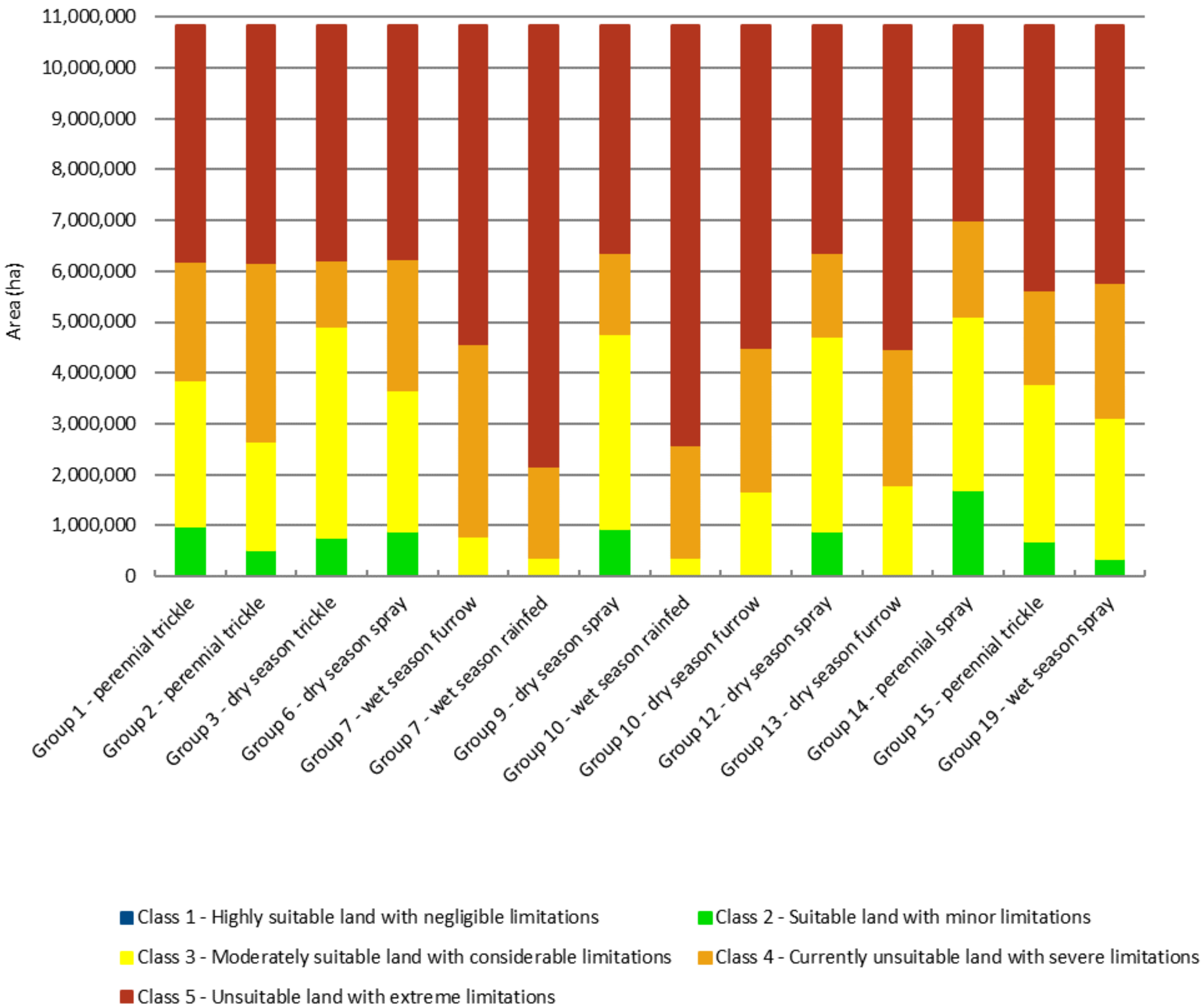

Figure 4-2 Area (ha) of the Southern Gulf catchments mapped in each of the land suitability classes for 14 selected land use combinations (crop group × season × irrigation type)

The five land suitability classes are described in Table 4-1 and more detail on the crop groups is given in Table 4-2.

In order to provide an aggregated summary of the land suitability products, an index of agricultural versatility was derived for the Southern Gulf catchments (Figure 4-3). Versatile agricultural land was calculated by identifying where the highest number of the 14 selected land use options presented in Figure 4-2 were mapped as being suitable (i.e. suitability classes 1 to 3).

Qualitative observations on each of the areas mapped as 'A' to 'F' in Figure 4-3 are provided in Table 4-3.

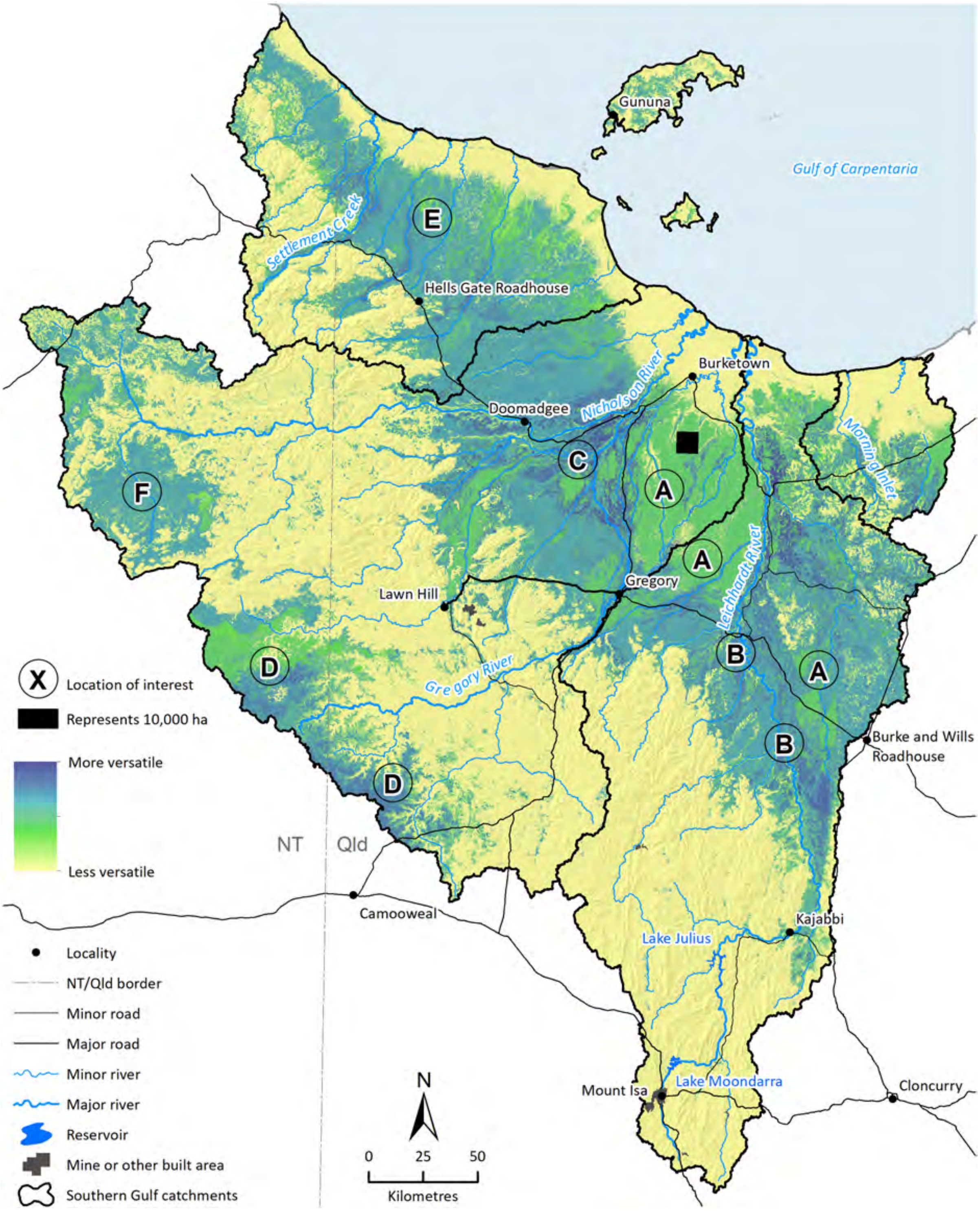

Figure 4-3 Agricultural versatility index map for the Southern Gulf catchments

High index values denote land that is likely to be suitable for more of the 14 selected land use options. The map shows specific areas of interest (A to F) from a land suitability perspective, which are discussed in Table 4-3. Note that the versality index mapped here does not consider flooding, risk of secondary salinisation or availability of water.

Table 4-3 Qualitative land evaluation observations in Southern Gulf catchments areas A to F shown in Figure 4-3

Further information on each soil generic group (SGG) and a map showing spatial distribution can be found in Section 2.3.

AREA	SOIL AND LOCATION	SOIL DESCRIPTION, POTENTIAL LAND USES AND LIMITATIONS
A	Cracking clay soils (SGG 9) of the Armraynald Plain formed from the Pleistocene Armraynald Beds and broad alluvial plains of the major rivers, particularly the Gregory and lower Leichhardt rivers	Comprises rarely flooded plains between the Gregory and Leichhardt rivers and regularly flooded plains on Lawn Hill Creek and between Gregory River and Running Creek. Soils are mainly moderately well-drained to imperfectly drained grey, brown or black cracking clay soils (SGG 9) with self-mulching to hard-setting structured surfaces. The imperfectly drained grey clay soils occur on the northern part of the Armraynald Plain and along Lawn Hill Creek. The brown cracking clays that occur on the south-eastern part of the plain east of the Leichhardt River can also be imperfectly drained. The soils may be suitable for furrow- or spray-irrigated vegetables (except root crops), rice, sugarcane and dry-season grain, forage, pulse crops, sweet corn and cotton. The main limitations are workability and potential wet-season flooding. Management of wet-season cropping needs to consider crop tolerance to seasonal wetness and flood duration, depth and frequency. How soil salinity will accumulate over time in these soils is currently unknown but must be monitored, especially in the imperfectly drained soils.
B	Friable non-cracking clays or sandy clay loams (SGG 2) and loam over relatively friable red clay subsoils (SGG 1.1) formed on alluvium along the middle reaches of the Leichhardt River	The friable non-cracking clays (SGG 2) are moderately well to well-drained, brown, red or grey, structured sandy clay loam or silty clay soils. The loam over red clay subsoils (SGG 1.1) are well drained with moderately thick (<0.2 m), loamy surface soils over red, structured clay subsoils developed on alluvium adjacent to the Leichhardt River. Soils are suitable for a range of spray- or trickle-irrigated vegetables, sugarcane, oilseed, sweet corn and wet-season and dry-season grain, forage, pulse crops and cotton. Wet-season tree crops are also likely to be suitable. Extents of suitable lands are generally minor, resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout. The main limitation is flooding post-cyclone. Soil erosion during flood events and compaction from tillage are land degradation risks.
C	Red loamy soils (SGG 4.1) and red sandy soils (SGG 6.1) occurring near Doomadgee on elevated narrow alluvial plains along the Nicholson River	The red loamy soils (SGG 4.1) occur downstream of Doomadgee on the southern side of the Nicholson River on a Pleistocene elevated floodplain. Soils are well-drained brown, silty loam moderately thick (<0.2 m) surface soils over red silty clay subsoils. Soils may be suitable for irrigated agriculture although the narrow tracts along the Nicholson River may limit infrastructure layout. Compaction from tillage is a land degradation risk. On the northern side of the Nicholson River, red sandy soils (SGG 6.1) have developed on an elevated alluvial plain near Doomadgee. Soils are well-drained red sand to sandy loams and have limited very low to low soil AWC, hence are only suited to irrigated horticulture using trickle or drip systems. There is a risk of deep drainage and nutrification of the adjacent river and groundwater table.
D	Grey cracking clays (SGG 9) from Cenozoic sediments on the Barkly Tableland	Soils are self-mulching, grey or occasionally brown, cracking clays (SGG 9), moderately deep (>1.0 m) to very deep (>1.5 m) and moderately well drained. Localised rockiness/stoniness in the soil profile may affect farming. Surfaces are gilgaied, and soils are formed of structured clay with calcareous nodules and gypsum crystals. Soils are suitable for trickle-irrigated mangoes and vegetables as well as wet-season cotton, grain and forage crops. Soil workability and rockiness are the main limitations, and deep gilgai microrelief may restrict land-levelling operations in some areas. There is a risk of water erosion on bare paddocks late in the dry season due to early rains.
E	Sandy soils (SGG 6.2) formed in sandy sediments on old lateritic surfaces of the Doomadgee Plains	Soils are brown, yellow or grey and sandy (SGG 6.2), highly permeable, well-drained, deep to very deep (1–1.5 m), commonly encountering ferricrete rock within 1 m. There is potential for irrigated horticulture using trickle or drip systems. In the absence of irrigation, agricultural potential of these soils is low. Soil depth and water-holding capacity are the main limitations.
F	Deep sandy soils (SGG 6) formed on an elevated sand plain in the Buddycurrawa Creek subcatchment of the Gulf Fall physiographic unit	Sandy soils are brown or red (SGG 6), highly permeable, moderately well to well-drained, and deep to very deep (>1.2 m). At depth these soils may be mottled and with no coarse fragments or nodules. The soil has a low AWC (<60 mm). There is potential for irrigated horticulture using trickle or drip systems. Agricultural potential of these soils is low without irrigation.

Land suitability and its implications for crop management are discussed in more detail for a selection of crops in Section 4.4, where land use suitability of a given crop and irrigation combination are mapped, along with information critical to the consideration of the crop in an irrigated farm enterprise. Land suitability maps for all 58 land use combinations are presented in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

4.3 Crop and forage opportunities in the Southern Gulf catchments

4.3.1 Introduction

This section presents results on the farm 'performance' of individual crop options, where performance is quantified specifically as crop yields, the amount of applied irrigation water (accounting for application efficiency) and GMs. Performance is presented with information on agronomic principles and farming practices to help interpret the viability of new (greenfield) farming opportunities in the Southern Gulf catchments. The individual crop options are grouped into rainfed broadacre, irrigated broadacre, irrigated horticulture and plantation tree crops (sections 4.3.3 to 4.3.7), and viability is discussed in a section on cropping systems (Section 4.3.8). That section considers the mix of farming opportunities and practices, for both single and sequential cropping systems, with the greatest potential to be profitably and sustainably integrated within the Southern Gulf catchments environments. Finally, Section 4.3.9 evaluates the viability of integrating irrigated forages into existing beef production. These farm-scale analyses are intended to be used in conjunction with the scheme-scale analyses of viability in Chapter 6 (as part of an integrated multi-scale analysis).

Nineteen irrigated crop options were selected to evaluate their potential performance in the Southern Gulf catchments (Table 4-4). The crops were selected to be compatible with the land suitability crop groups (Table 4-2), provided that: (i) they had the potential to be viable in the Southern Gulf catchments (based on knowledge of how well these crops grow in other parts of Australia), (ii) they were of commercial interest for possible development in the region and (iii) there was sufficient information on their agronomy, and farming costs and prices, for quantitative analysis. The analyses used a combination of Agricultural Production Systems sIMulator (APSIM) crop modelling and climate-informed extrapolation to estimate potential yield and water use for each crop. Those values were then used in a farm GM tool specifically designed for greenfield farming developments (like those in the Southern Gulf catchments, where there are very few existing commercial farms or farm financial models). In particular, extrapolations used close similarities in climate and soils between possible cropping locations in the Southern Gulf catchments and established irrigated cropping regions at similar latitudes near the Ord River Irrigation Area (WA) and the Mareeba–Dimbulah Irrigation Area (Queensland) (Figure 4-4). Full details of the approach are described in the companion technical report on agricultural viability and socio-economics (Webster et al., 2024). Section 4.4 provides further details on opportunities and constraints in the Southern Gulf catchments, for example, crops in each of the agronomic crop types listed in Table 4-4.

Table 4-4 Crop options for which performance was evaluated in terms of water use, yields and gross margins

The methods used for estimating crop yield and irrigation water requirements are coded as: A = APSIM; E = climate-informed extrapolation. 'A, E' indicates that A is the primary method and E is used for sensibility testing. 'E, A' indicates that E is the primary method and A is used for applying adjustments. 'Mango (KP)' is Kensington Pride and 'Mango (PVR)' is an indicative new high-yielding variety likely to have plant variety rights (e.g. Calypso). Note that crops that are agronomically similar in terms of the commodities they produce (as categorised in the table) may differ in how they respond to soil constraints. The crop type categories in the table are therefore necessarily different to the crop groups used in the land suitability section (which are grouped according to shared soil requirements and constraints; Table 4-2).

CROP TYPE	CROP	IRRIGATION WATER ESTIMATE METHOD	YIELD ESTIMATE METHOD
Broadacre			
Cereal	Sorghum (grain)	A, E	A, E
	Maize	A, E	A, E
Pulse	Mungbean	A, E	A, E
	Chickpea	A, E	A, E
	Soybean	A, E	A, E
Oilseed	Sesame	E	E
	Peanut	A, E	A, E
Industrial	Cotton (dry season)	A, E	A, E
	Cotton (wet season)	A, E	A, E
	Hemp	E	E
Forage	Rhodes grass	A, E	A, E
Horticulture (row)	Rockmelon	E	E
	Watermelon	E	E
	Onion	E	E
	Capsicum	E	E
Horticulture (tree)	Mango (PVR)	E	E
	Mango (KP)	E	E
	Lime	E	E
Plantation tree	African mahogany	E	E

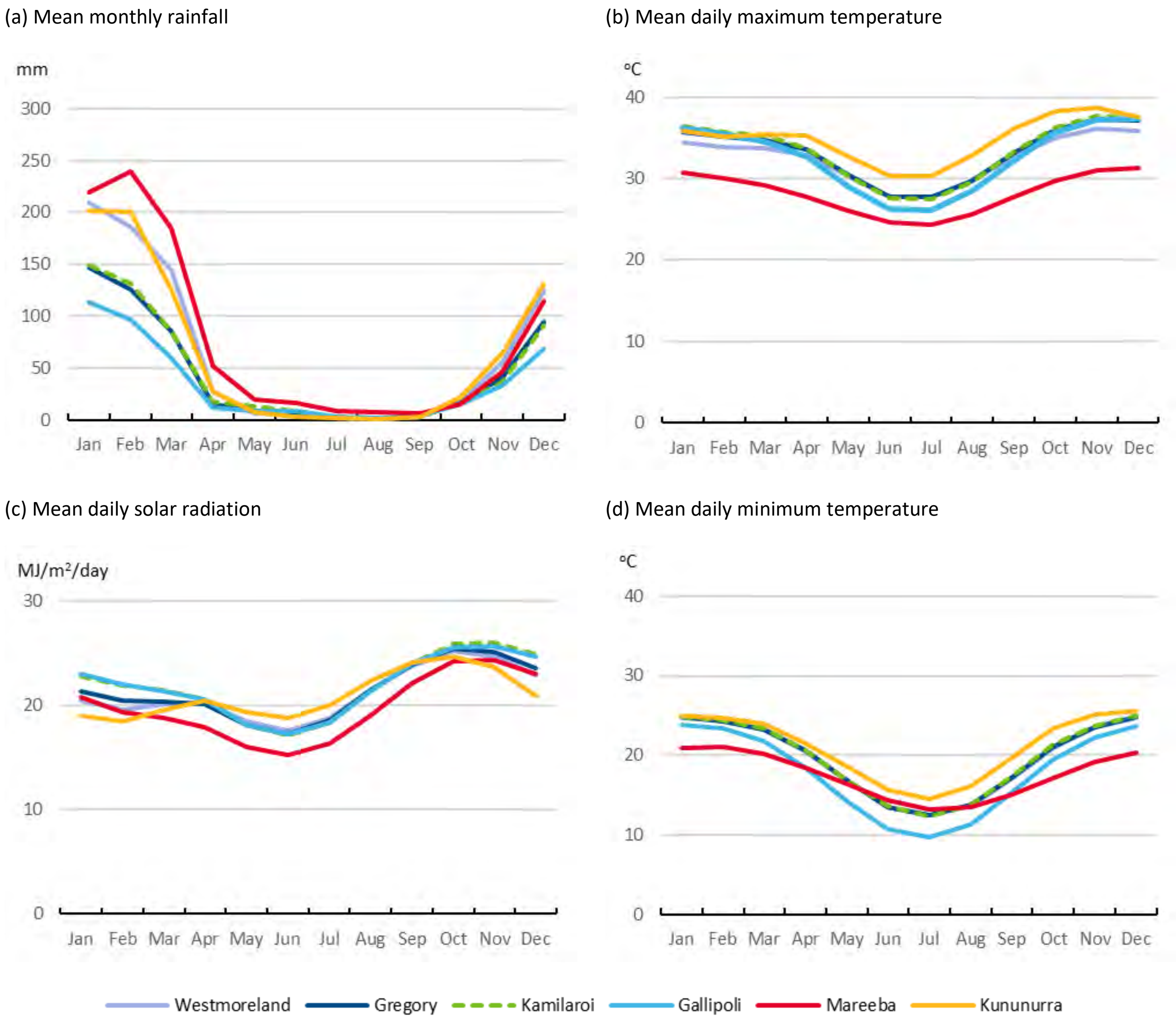

Figure 4-4 Climate comparisons of Southern Gulf catchments' sites with established irrigation areas at Kununurra (WA) and Mareeba (Queensland)

Southern Gulf catchments sites are Westmoreland, Gregory, Kamilaroi and Gallipoli.

Four locations were selected for the APSIM simulations to represent some of the best potential farming conditions across the varied environments in the Southern Gulf catchments:

- A Vertosol with a Gregory (–18.65°S, 139.25°E) climate. This soil represents the farming conditions of the lowland cracking clays (SGG 9; marked 'A' in Figure 4-3) and are the most extensive arable areas in the Southern Gulf catchments. During the wet-season, access and limitations from floodplain inundation and workability may constrain cropping. Using grain sorghum as an indicator crop, the plant available water capacity (PAWC) of the modelled soil was 212 mm (noting that PAWC differs between crops with different rooting patterns and physiologies). Daily historical meteorological data used for these simulations was from the Gregory weather station, which has a mean annual rainfall of about 540 mm.
- A Chromosol with a Kamilaroi (–19.36°S, 140.04°E) climate. This soil represents some of the better farming conditions among the friable non-cracking clay soils (SGG 1 and Dermosols, SGG 2; marked 'B' in Figure 4-3) along the middle reaches of the Leichhardt River. The PAWC of this soil for grain sorghum was 93 mm, and the mean annual rainfall for Kamilaroi is about 577 mm.

- A red Kandosol with a Westmoreland (–17.34°S, 138.25°E) climate. This soil represents some of the better farming conditions among the loamy soils (SGG 4; marked ‘C’ in Figure 4-3), found on elevated narrow alluvial plains along the Nicholson River and near Doomadgee. The PAWC of this soil for grain sorghum was 129 mm, and the mean annual rainfall for Westmoreland is about 780 mm.
- A Vertosol with a Gallipoli (–19.14°S, 137.87°E) climate. This soil represents some of the better farming conditions among the cracking clay soils (SGG 9; marked ‘D’ in Figure 4-3), having less wet-season issues than the Gregory (lowland) cracking clay soils, although surface and profile rock may limit some areas. The PAWC of this soil for grain sorghum was 146 mm, and the mean annual rainfall for Gallipoli is about 420 mm.

To assist with interpreting the later results, some information is first provided on agronomic principles related to the scheduling of critical farm operations such as sowing and irrigation in relation to Southern Gulf catchments environments.

4.3.2 Cropping calendar and time of sowing

Time of sowing can have a significant effect on achieving economical crop and forage yields, and on the availability and amount of water for irrigation required to meet crop demand. Cropping calendars identify optimum sowing times of different crops and are essential tools for scheduling farm operations (Figure 4-5) so that crops can be reliably and profitably grown. No cropping calendar existed for the Southern Gulf catchments before the Assessment.

Sowing windows vary in both timing and length among crops and regions, and they consider the likely suitability and constraints of weather conditions (e.g. heat and cold stress, radiation, and conditions for flowering, pollination and fruit development) during each subsequent growth stage of the crop. Limited field experience currently exists in the Southern Gulf catchments for most of the crops and forages evaluated. This cropping calendar (Figure 4-5) is therefore based on knowledge of crops derived from past and current agricultural experience in the Ord River Irrigation Area (WA), Katherine and Douglas–Daly regions (NT), Mareeba–Dimbulah Water Supply Scheme and the Burdekin region (Queensland).

Some annual crops have both wet-season and dry-season cropping options. Perennial crops are grown throughout the year, so growing seasons and planting windows are less well defined. Generally, perennial tree crops are transplanted as small plants, and in northern Australia this is usually timed towards the beginning of the wet season to take advantage of wet-season rainfall. The cropping calendar presented here considers the optimal climate conditions for crop growth and considers operational constraints specific to the local area. Such constraints include wet-season difficulties in access and trafficability, and limitations on the number of hectares that available farm equipment can sow/plant. For example, clay-rich alluvial Vertosols, such as those found across the Armraynald and Cloncurry plains and Barkly Tableland, are likely to present severe trafficability constraints through much of the wet season in the Southern Gulf catchments, while sandier Kandosols would present far fewer trafficability restrictions in scheduling farming operations (Figure 4-6).

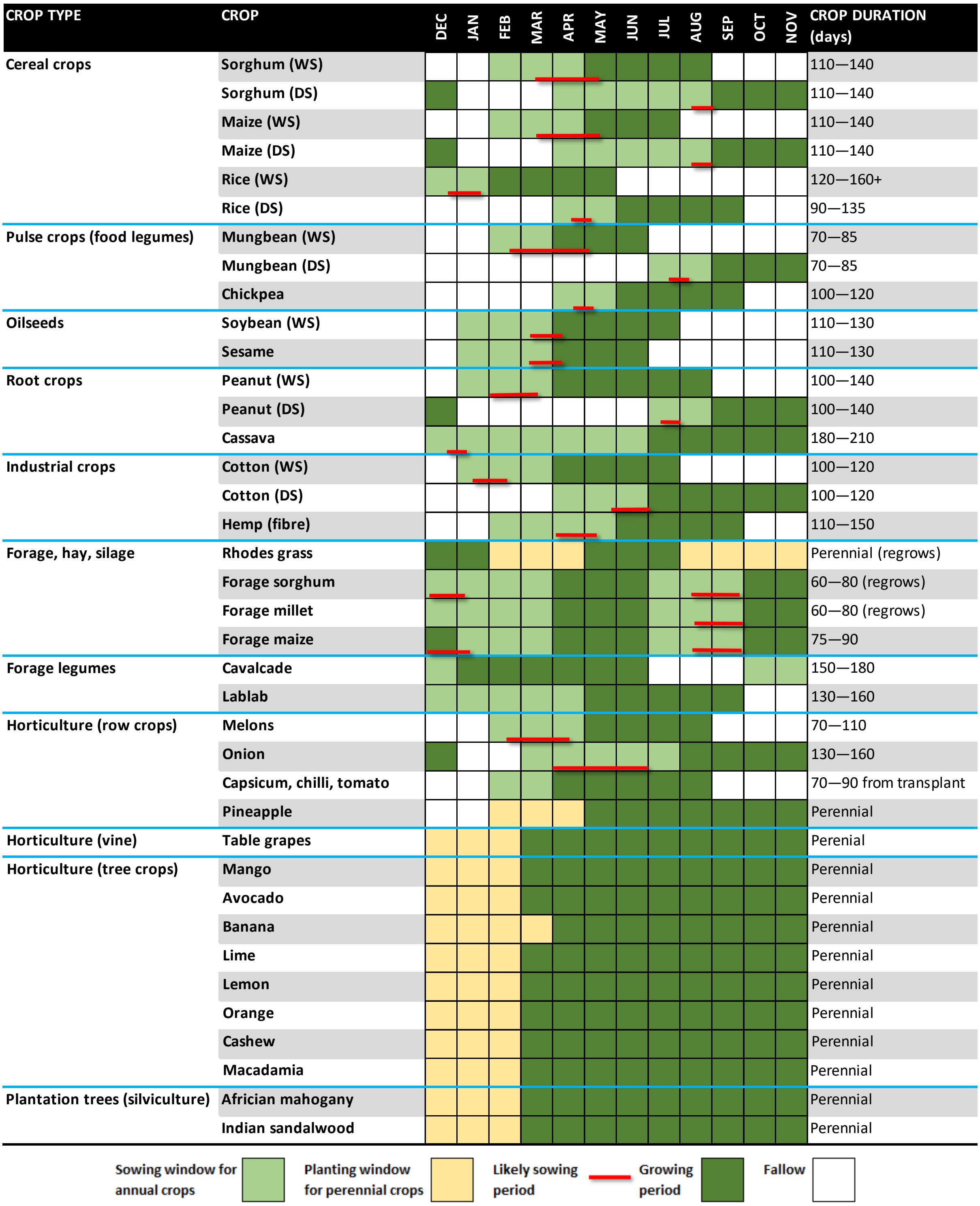

Figure 4-5 Annual cropping calendar for irrigated agricultural options in the Southern Gulf catchments

WS = wet season; DS = dry season.

Many suitable annual crops can be grown at any time of the year with irrigation in the Southern Gulf catchments. Optimising crop yield alone is not the only consideration. Ultimately, sowing date selection must balance the need for the best growing environment (optimising solar radiation and temperature) with water availability, pest avoidance, trafficability during the growing season and at harvest, crop rotation, supply chain requirements, infrastructure development costs, market access considerations and potential commodity price. Many summer crops from temperate regions are suited to the tropical dry season (winter) because temperatures are closer to their optima and/or there is more consistent solar radiation (e.g. maize (*Zea mays*), chickpea (*Cicer arietinum*) and rice (*Oryza sativa*)). For sequential cropping systems (which grow more than a single crop in a year in the same field), growing at least one crop partially outside its optimal growing season can be justified if this increases total farm profit per year and there are no adverse biophysical consequences (e.g. pest build-up).

(a) (b)

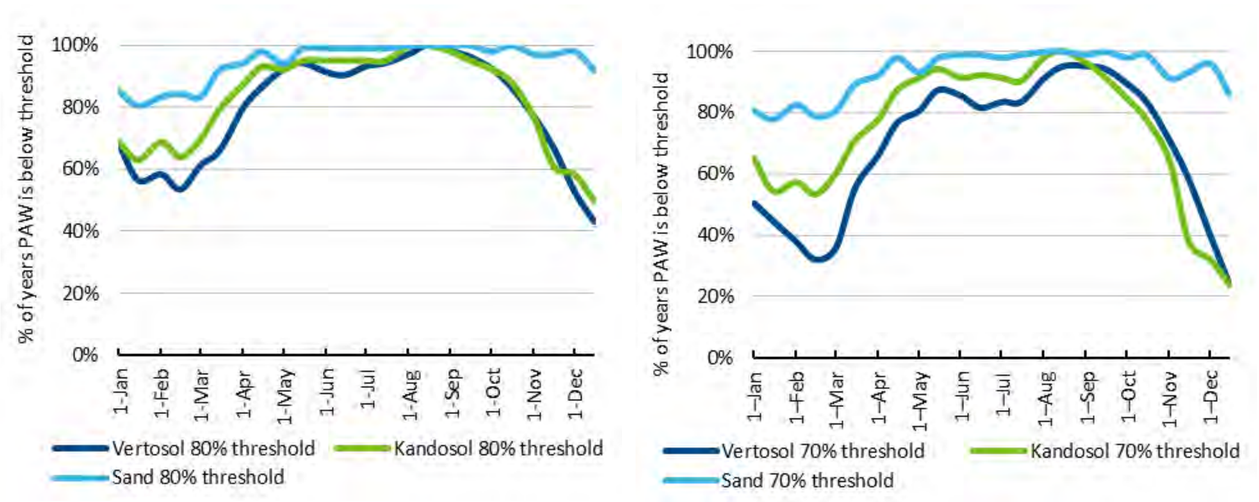

Figure 4-6 Soil wetness indices that indicate when seasonal trafficability constraints are likely to occur on sands, Kandosols (loamy sands) and Vertosols (high clay) with a Gregory climate for two thresholds (a) 80% and (b) 70% of the maximum plant available water capacity

The indices show the proportion of years (for dates at bi-monthly intervals) when plant available water (PAW) in the top 30 cm of the soil is below two threshold proportions (70% and 80%) of the maximum plant available water capacity value. Lower values indicate there would be fewer days at that time of year when fields would be accessible and trafficable. Estimates are from 100-year Agricultural Production Systems Simulator simulations without a crop. In actual farming situations, once a crop canopy is established later in the season, crop water extraction from the soil would assist in alleviating these constraints.

Growers also manage time of sowing to optimally use stored soil water and in-season rainfall, and to avoid rain damage at maturity. In the Southern Gulf catchments mean monthly rainfall is highly variable between the wet and dry seasons (Figure 4-4) and irrigation allows growers the flexibility in sowing date and in the choice and timing of crop or forage systems in response to seasonal climate conditions. Depending on the rooting depth of a particular species and the length of growing season, crops established at the end of the wet season may access a full profile of soil water (e.g. ≥200 mm PAWC for some Vertosols). While timing sowing to the end of the wet season to take advantage of soil water may reduce the overall irrigation requirement, it may expose crops to periods of unfavourable solar radiation or temperatures during plant development and flowering. It may also prevent the implementation of a sequential cropping system.

4.3.3 Rainfed cropping

Rainfed cropping (crops grown without irrigation, relying only on rain) has been practised by farmers in the NT and Queensland for almost 100 years, yet only small areas of rainfed crop production currently occur each year in the very remote northern regions. This indicates that, despite the theoretical possibility of producing rainfed crops using the significant wet-season rainfall in the Southern Gulf catchments, in practice significant agronomic and market-related challenges to rainfed crop production have prevented its expansion to date.

Without the certainty provided by irrigation, rainfed cropping is opportunistic in nature, relying on favourable conditions in which to establish, grow and harvest a crop. The annual cropping calendar in Figure 4-5 shows that, for many crops, the sowing window includes the month of February. For relatively short-season crops, such as forage sorghum and mungbean (*Vigna radiata*), this coincides with both the sowing time that provides close to maximum crop yield and the time at which the season's water supply can be accessed with a high degree of confidence. Table 4-5 shows how plant available soil water content at sowing and subsequent rainfall in the 90 days after each sowing date varies over three different sowing dates for a Vertosol in the Southern Gulf catchments at Gregory. As sowing is delayed from February to April, the amount of stored soil water decreases. However, there is a significant decrease in rainfall in the 3 months after sowing. Combining the median PAW in the soil profile at sowing, and the median rainfall received in the 90 days following sowing, provides totals of 392, 250 and 183 mm for the February, March and April sowing dates, respectively. For drier-than-average years (80% probability of exceedance), the soil water stored at sowing and the expected rainfall in the ensuing 90 days (<260 mm) would result in water stress and comparatively reduced crop yields. In wetter-than-average years (20% probability of exceedance) the amount of soil water at the end of February combined with the rainfall in the following 90 days (527 mm) is sufficient to grow a good short-season crop (noting that the timing of rainfall is also important because some rain is 'lost' to runoff, evaporation and deep drainage between rainfall events). Opportunistic rainfed cropping would target those wetter years where PAW at the time of sowing indicated a higher chance of harvesting a profitable crop.

Table 4-5 Soil water content at sowing, and rainfall for the 90-day period following sowing for three sowing dates, based on a Gregory climate on a Vertosol

The 80%, 50% (median) and 20% probabilities of exceedance values are reported for the 100 years between 1920 and 2020. The lower-bound values (80% exceedance) occur in most years, while the upper-bound values only occur in the most exceptional upper 20% of years. PAW = plant available water stored in soil profile.

SOWING DATE	PAW AT SOWING DATE (mm)			RAINFALL IN 90 DAYS FOLLOWING SOWING DATE (mm)			TOTAL STORED SOIL WATER + RAINFALL IN SUBSEQUENT 90 DAYS (mm)		
	80%	**50%**	**20%**	**80%**	**50%**	**20%**	**80%**	**50%**	**20%**
1 February	111	176	220	132	200	308	260	392	527
1 March	133	178	208	24	78	180	171	250	369
1 April	120	173	193	0	6	58	136	183	240

Figure 4-7 highlights the impact on rainfed crop yields of the diminishing water availability from early to late wet-season planting. This constraint is much more severe for sandier soils that have less capacity to store PAW (like Kandosols on the Doomadgee Plain in the Southern Gulf catchments, Figure 4-7a), than finer textured soils (like the alluvial Vertosols in the Southern Gulf catchments, Figure 4-7b). However, the frequent inundation and waterlogging of clay soils, which are often located adjacent to rivers, means that crops cannot always be sown at optimum times; fertiliser can be lost due to runoff, drainage and denitrification; and in-crop management (e.g. for weed, disease and insect control) cannot be undertaken cost-effectively with ground-based equipment in a timely manner, a critical requirement for rainfed crop production to succeed.

Those disruptions decrease the chance that high potential yields in the top 20% of the seasons could be achieved in practice.

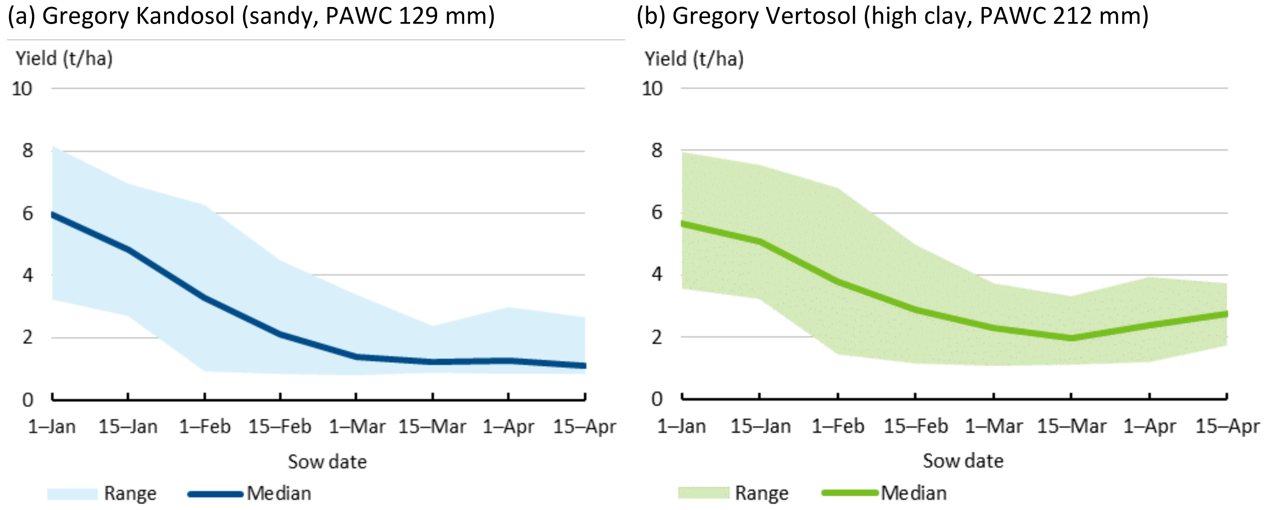

Figure 4-7 Influence of planting date on rainfed grain sorghum yield at Gregory for a (a) Kandosol and (b) Vertosol
Estimates are from Agricultural Production Systems Simulator simulations with planting dates on the 1st and 15th of each month. The shaded band around the median line indicates the 80% to 20% exceedance probability range in year-to-year variation. PAWC = plant available water capacity of given soil profile.

Seldom is soil uniform within a single paddock, let alone across entire districts. Without the homogenising input of irrigation to alleviate water limitations (and associated high inputs of fertilisers to alleviate nutrient limitations), yields from low-input rainfed cropping are typically much more variable (both across years and locations) than yields from irrigated agriculture. Furthermore, the capacity of the soil to supply stored water varies with soil type, and it also depends on crop type and variety because each crop's root system has a different ability to access water, particularly deep in the profile. This makes it harder to make generalisations about the viability of rainfed cropping in the Southern Gulf catchments as farm performance (e.g. yields and GMs) is much more sensitive to slight variations in local conditions. Rigorous estimates of rainfed crop performance, on which investment decisions could be confidently made, would require detailed localised soil mapping and crop trials.

Despite the challenges described above, recent efforts have identified potential opportunities for rainfed farming using higher-value crops, such as pulses or cotton, in northern Australia. A preliminary APSIM assessment of the potential for rainfed cotton in the Katherine region suggested that mean lint yields of 2.5 to 3.5 bales per ha may be possible at a range of locations in the vicinity of the Southern Gulf catchments (Yeates and Poulton, 2019). However, there was very high variability in median yields between farms (1–5 bales/ha), depending on management and soil type.

4.3.4 Irrigated crop response and performance metrics

Crops that are fully irrigated can yield substantially more than rainfed crops. Figure 4-8 shows how modelled yields for grain sorghum grown on Vertosols in the Southern Gulf catchments increase as more water becomes available to alleviate water limitations and meet increasing proportions of crop demand. With sufficient irrigation, yields are highest for crops grown over the dry season when radiation tends to be less limiting comparing plateau of lines in Figure 4-8a and Figure 4-8b. For wet-season sowing, unirrigated yields can approach fully irrigated yields in good years (yields exceeded in the top 20% of years, marked by the upper shaded range in Figure 4-8a). However, irrigation allows greater flexibility in sowing dates, allows sowing in the dry season too (for crops that would then grow through the wet season) and generates more reliable (and higher median) yields.

The simulations did not seek to 'optimise' supplemental irrigation strategies in years where available water was insufficient to maximise crop yields; irrigators would need to make those decisions in years where available water was lower than total crop demand. A key advantage of irrigated dry-season cropping in northern Australia is that the availability of water in the soil profile and surface water storages is largely known at the time of planting (in the early wet season; Table 4-5). This means irrigators have good advance knowledge for planning how much area to plant, which crops to grow and which irrigation strategies to use, particularly in years where they have insufficient water to fully irrigate all fields. A mix of irrigation approaches could be used, such as expanding the scale of a core irrigated cropping area with other less intensively farmed areas, opportunistic rainfed cropping, opportunistic supplemental irrigation, opportunistic sequential cropping and/or adjusting the area of fully irrigated crops grown to match available water supplies that year.

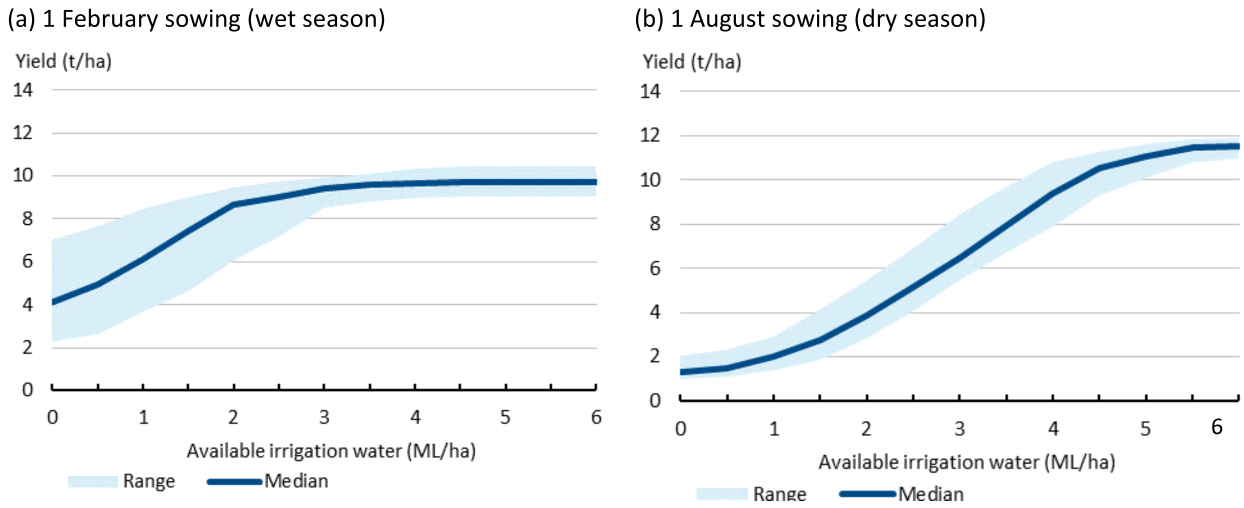

Figure 4-8 Influence of available irrigation water on grain sorghum yields for planting dates of (a) 1 February and (b) 1 August, for a Vertosol with a Gregory climate

Estimates are from 100-year Agricultural Production Systems Simulator simulations. The shaded band around the median line indicates the 80% to 20% exceedance probability range in year-to-year variation. Rainfed production is indicated by the zero point, where no allocation is available for irrigation.

Measures of farm performance (in terms of yields, water use and GMs) are presented for the 19 cropping options that were evaluated (Table 4-4). Given the limited commercial irrigated farming currently occurring in the Southern Gulf catchments that can provide real-world data, estimates of crop water use and yields should be considered as indicative, and to have a possible 20% margin of error at the catchment scale (with further variation expected between farms and fields). The measures of performance should be considered as an upper bound of what could be achieved under best-practice management after learning and adapting to location-specific conditions.

GMs are a key partial metric of farm performance but should not be treated as fixed constants determined by the cropping system alone. They are a product of the farming and business management decisions made by individual farmers, input prices, commodity prices and market opportunities (details on calculation of GMs are in Webster et al., 2024). As such, the GMs presented in Table 4-6 should be treated as indicative of what might be attained for each cropping option once its sustainable agronomic potential has been achieved. Any divergence from assumptions about yields and costs would flow through to GM values, as would the consequences of any underperformance or overperformance in farm management. It is unrealistic to assume that the levels of performance in the results below would be achieved in the early years of newly established farms, and allowance should be made for an initial period of learning when yields and GMs are below their potential (see Chapter 6). Collectively however, the GMs and other performance metrics presented here provide an objective and consistent comparison across a suite of likely cropping options for the Southern Gulf catchments, and indicate a maximum performance that could be achievable for greenfield irrigated development for each of the groupings of crops in sections 4.3.5 to 4.3.7.

4.3.5 Irrigated broadacre crops

Table 4-6 shows the farm performance (yields, water use and GMs) for the ten broadacre cropping options that were evaluated. For crops that were simulated with APSIM, estimates are provided for locations with four different soil types associated with climates in the Southern Gulf catchments (Kandosol at Westmoreland, Vertosol at Gregory, Chromosol at Kamilaroi and Vertosol at Gallipoli) and include measures of variability (expressed in terms of years with yield exceedance probabilities of 80%, 50% (median) and 20%). For other crops, yield and water use estimates (and resulting GMs) were estimated based on expert experience and climate-informed extrapolation from the most similar analogue locations in northern Australia where commercial production currently occurs.

The broadacre cropping options with the best GMs (>$2000/ha) were cotton (both wet-season and dry-season cropping), forages (Rhodes grass (*Chloris gayana*)) and peanuts (on a Chromosol). These suggest GMs up to $4500/ha might be achievable for broadacre cropping in the Southern Gulf catchments, although not necessarily at scale.

Simulated yields (and consequent GMs) were generally lowest on the Kandosol and highest on the heavy Vertosol because of the increased buffering capacity that a high PAWC clay soil provides against hot weather, which triggers water stress even in irrigated crops. The Chromosol yields and GMs were slightly lower than the Vertosol due to its lower PAWC. With Vertosols in the Southern Gulf catchments there could be drainage challenges (Figure 4-6) that could limit the suitable area for farming and may require more careful management than Vertosols that are currently used for cotton farming in other parts of Australia.

A breakdown of the variable costs for growing broadacre crops shows that the largest costs are the costs of inputs (mean 28%), farm operations (mean 33%) and marketing (mean 28%) (Table 4-7). The input and operations cost categories would have similar dollar values when growing the same crop in southern parts of Australia, but the cost category that is higher and thus puts northern growers at a disadvantage is market costs (freight and other costs involved in selling the crop). Total variable costs consume 84% of the gross revenue generated, which leaves margin for profitable farms to be able to temporarily absorb small declines in commodity prices or yields without creating severe cashflow problems.

Table 4-6 Performance metrics for broadacre cropping options in the Southern Gulf catchments: applied irrigation water, crop yield and gross margin (GM) for four environments

Performance metrics indicate the upper bound that could be achieved after best management practices for Southern Gulf catchments environments had been identified and implemented. All options are for dry-season (DS) irrigated crops sown between March and May (end of the wet season (WS)), except for the WS cotton, sown in mid-February and DS cotton sown in mid-June. Our modelled results suggest that dry-season planting of cotton in mid-June at Gallipoli led to a high incidence of crop failure and is not shown. Variance in yield estimates from Agricultural Production Systems sIMulator (APSIM) simulations is indicated by providing 80%, 50% (median) and 20% probability of exceedance values (Y80%, Y50% and Y20%, respectively), together with associated applied irrigation water (including on-farm losses) and GMs in those years. The lower-range yields (Y80% exceedance) occur in most years, while the upper-range Y20% yields only occur in the most exceptional upper 20% of years. Note that applied irrigation water is not always higher in years with higher yields (Y20%). 'na' indicates 20% and 80% exceedance estimates that were not applicable because APSIM outputs were not available and expert estimates of just the median yield and water use were used instead. Peanut is omitted for the Vertosol location because of the practical constraints of harvesting root crops on clay soils. Freights costs assume processing near Cloncurry for cotton and Townsville for peanut, and that hay is sold locally. No crop model was available for sesame or hemp, so indicative estimates for the catchments were used. Cotton yields and prices are for lint bales (227 kg after ginning), not tonnes, and account for a lint turnout of 40% and a cotton seed price of $280/t. PAWC = plant available water capacity.

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	**Y50%**	**Y20%**	**Y80%**	**Y50%**	**Y20%**					**Y80%**	**Y50%**	**Y20%**
Red Kandosol (129 mm PAWC), Westmoreland climate (~780 mm annual rainfall)													
Cotton (WS)	4.5	5.3	5.7	8.6	9.4	10	bales/ha	700	4,159	7,415	2,784	3,256	3,683
Cotton (DS)	5.0	5.4	5.9	3.7	5.0	6	bales/ha	700	3,230	3,939	–24	708	1,554
Sorghum (grain)	5.2	5.6	6.0	8.5	9.0	10	t/ha	350	3,779	3,164	–641	–615	–597
Mungbean	3.6	3.9	4.3	1.5	1.8	2	t/ha	1,200	1,417	1,958	323	540	720
Chickpea	2.2	2.3	2.6	0.3	0.3	0	t/ha	750	1,019	254	–776	–765	–732
Soybean	5.6	5.9	6.4	3.3	3.5	4	t/ha	650	2,139	2,265	107	125	182
Peanut	4.0	4.5	4.9	5.1	5.5	6	t/ha	1,000	4,849	5,455	483	607	810
Rhodes grass (hay)	13.7	15.3	16.9	38.1	39.2	41	t/ha	220	5,672	8,624	3,032	2,952	3,005
Maize	5.5	5.8	6.1	8.9	9.3	10	t/ha	380	3,857	3,530	–291	–328	–308
Heavy Vertosol (212 mm PAWC), Gregory climate (~540 mm annual rainfall)													
Cotton (WS)	4.1	4.7	5.2	9.7	10.7	11	bales/ha	700	3,857	8,425	3,986	4,536	4,950

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	**Y50%**	**Y20%**	**Y80%**	**Y50%**	**Y20%**					**Y80%**	**Y50%**	**Y20%**
Cotton (DS)	5.2	5.9	6.3	5.0	6.8	9	bales/ha	700	3,889	5,354	1,066	2,096	3,378
Sorghum (grain)	5.2	5.8	6.5	10.0	10.5	11	t/ha	350	3,259	3,671	358	298	348
Mungbean	3.2	3.8	4.4	1.6	1.9	2	t/ha	1,200	3,373	2,068	559	794	968
Chickpea	3.2	3.8	3.9	1.9	2.2	3	t/ha	750	1,275	1,650	90	227	436
Soybean	7.6	8.6	9.3	4.7	5.0	5	t/ha	650	1,423	3,223	913	998	1,109
Rhodes grass (hay)	17.6	20.5	22.3	44.9	45.9	47	t/ha	220	6,566	10,096	3,648	3,530	3,474
Maize	6.7	7.2	7.9	9.6	10.0	10	t/ha	380	3,299	3,800	445	501	544
Chromosol (92 mm PAWC), Kamilaroi climate (~577 mm)													
Cotton (WS)	4.7	5.4	5.8	9.3	10.5	12	bales/ha	700	3,697	8,268	3834	4,571	5,195
Cotton (DS)	6.3	6.9	7.4	4.7	6.6	8	bales/ha	700	3,183	5,197	815	2,014	2,892
Sorghum (grain)	5.7	6.4	6.9	10.5	11.1	12	t/ha	350	3,159	3,885	657	726	809
Mungbean	3.5	4.1	4.5	1.6	1.9	2	t/ha	1,200	1,253	2,101	608	848	1,090
Chickpea	2.4	2.7	3.3	0.8	1.1	1	t/ha	750	1,128	788	–445	–340	–218
Soybean	7.3	7.8	8.4	4.0	4.2	4	t/ha	650	1,949	2,703	687	754	826
Peanut	5.3	5.8	6.2	6.3	6.9	7	t/ha	1,000	4,766	6,900	1,793	2,134	2,359
Rhodes grass (hay)	20.0	22.4	24.3	45.2	46.3	47	t/ha	220	6,946	10,195	3,319	3,249	3,175
Maize	6.5	6.9	7.3	9.3	9.8	10	t/ha	380	2,937	3,706	700	769	833
Light Vertosol (146 mm PAWC), Gallipoli climate (~420 mm)													
Cotton (WS)	4.3	4.9	5.4	5.6	7.6	9	bales/ha	700	3,324	5,984	1414	2,660	3,581
Sorghum (grain)	6.5	7.4	7.9	11.1	11.6	12	t/ha	350	3,521	4,076	499	555	603
Mungbean	4.0	4.5	5.0	1.8	2.0	2	t/ha	1,200	1,306	2,212	700	906	1,104
Chickpea	3.5	4.1	4.5	1.9	2.3	3	t/ha	750	1,416	1,692	117	276	538
Soybean	8.8	9.4	10.1	4.8	5.0	5	t/ha	650	2,213	3,240	947	1,026	1,082

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	**Y50%**	**Y20%**	**Y80%**	**Y50%**	**Y20%**					**Y80%**	**Y50%**	**Y20%**
Rhodes grass (hay)	24.4	22.4	24.4	45.0	46.3	47	t/ha	220	6,829	10,179	4,575	3,350	3,327
Maize	6.1	8.0	8.5	9.7	10.2	11	t/ha	380	3,256	3,895	203	638	675
General estimate for Southern Gulf catchments (not soil specific)													
Sesame	na	5.3	na	na	0.9	na	t/ha	1,300	2,041	1,170	na	–871	na
Hemp (grain seed)	na	5.0	na	na	1.1	na	t/ha	3,150	2,519	3,465	na	946	na

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Table 4-7 Breakdown of variable costs relative to revenue for broadacre crop options

The first eight crops (Cotton (WS) to Rhodes grass) are for the Chromosol, Kamilaroi climate (intermediate performance), and the last three crops are for general catchment estimates. 'Input' costs are mainly for fertilisers, herbicides and pesticides; the cost of farm 'operations' includes harvesting; 'labour' costs are the variable component (mainly seasonal workers) not covered in fixed costs (mainly permanent staff); 'market' costs include levies, commission and transport to the point of sale. WS = wet season; DS = dry season.

CROP	TOTAL REVENUE	TOTAL VARIABLE COSTS	PERCENTAGE BREAKDOWN OF VARIABLE COSTS				VARIABLE COSTS VS REVENUE
	($/ha/y)	($/ha/y)	INPUTS (%)	OPERATIONS (%)	LABOUR (%)	MARKET (%)	(%)
Cotton (WS)	8,268	3,697	37%	37%	7%	19%	45%
Cotton (DS)	5,197	3,183	43%	34%	9%	14%	61%
Sorghum (grain)	3,885	3,159	15%	13%	8%	63%	81%
Mungbean	2,101	1,253	31%	24%	15%	29%	60%
Chickpea	788	1,128	38%	29%	15%	17%	143%
Soybean	2,703	1,949	27%	20%	14%	39%	72%
Peanut	6,900	4,766	25%	42%	5%	27%	69%
Rhodes grass (hay)	10,195	6,946	12%	68%	7%	13%	68%
Maize	3,706	2,937	16%	14%	10%	60%	79%
Sesame	1,170	2,041	30%	47%	10%	13%	174%
Hemp (grain seed)	3,465	2,519	39%	39%	10%	12%	73%
Mean	**4,398**	**3,053**	**28%**	**33%**	**10%**	**28%**	**84%**

Risk analyses were conducted for the two broadacre crops with the highest GMs: cotton and forages. The risk analysis used a narrative approach, where variable values with the potential to be different from those used in the GMs were varied and new GMs calculated. The narrative approach allows the impact of those variables to be determined. The cotton analysis explored the sensitivity of GMs to opportunities and challenges created by changes in cotton lint prices, crop yields and distance to the nearest gin (Table 4-8). Results show that high recent cotton prices (about $800/bale through 2022) have created a unique opportunity for those looking to establish new cotton farms in NT locations like the Victoria catchment, since growers could transport cotton to distant gins or produce suboptimal yields and still generate GMs above $3000/ha. At lower cotton lint prices, a local gin becomes more important for farms to remain viable. High cotton prices and the opening of a cotton gin 30 km north of Katherine in December 2023 have reduced some of the risk involved in learning to grow cotton as GMs increase from both these developments. At high yields and prices, the returns per megalitre of irrigation water may favour growing a single cotton crop per year, instead of committing limited water supplies to sequential cropping with a dry-season crop (that would likely provide lower returns per megalitre and be operationally difficult/risky to sequence).

Table 4-8 Sensitivity of cotton crop gross margins ($/ha) to variation in yield, lint prices and distance to gin

The base case is the Gregory heavy Vertosol (Table 4-6) and is highlighted for comparison. The gin locations considered are a local gin near a new cotton farming region in the Southern Gulf catchments near Gregory, a hypothetical gin in Cloncurry, and the existing gin in Emerald, Queensland. Cotton lint prices include a low price for 2015–2020 ($580/bale), a mean price for 2020–2024 ($700/bale) and a high price for 2015–2020 ($900/bale). Effects of a lower yield are also tested (the base case of 10.7 bales/ha for wet-season cropping versus the 6.8 bales/ha estimated as the dry-season yield for this location).

FREIGHT COST/TONNE (DISTANCE TO GIN)	COTTON CROP GROSS MARGIN ($/ha)					
	LINT PRICE = $580/bale		LINT PRICE = $700/bale		LINT PRICE = $900/bale	
	YIELD		YIELD		YIELD	
	10.7 bales/ha	6.8 bales/ha	10.7 bales/ha	6.8 bales/ha	10.7 bales/ha	6.8 bales/ha
$13 (50 km to local gin)	3732	1613	5016	2429	7156	3789
$92 (330 km to Cloncurry gin)	3532	1308	4536	2124	6676	3484
$243 (1250 km to Emerald gin)	2335	725	3619	1541	5759	2901

The narrative risk analysis for irrigated forages also looked at the sensitivity of farm GMs to variations in hay price and distance to markets, but here focuses on the issues of local supply and demand (Table 4-9). Forages, such as Rhodes grass, are a forgiving first crop to grow on greenfield farms as new farmers gain experience of local cropping conditions and ameliorate virgin soils while producing a crop with a ready local market in cattle. While there are limited supplies of hay in the region, growers may be able to sell hay at a reasonable price, given the large amount of beef production in the Southern Gulf catchments and challenges of maintaining livestock condition through the dry season, when the quality of native pastures is low. The scale of unmet local demand for hay limits opportunities for expansion of hay production without depressing local prices and/or having to sell hay further away, both of which lead to rapid declines in GMs (to below zero in many cases; Table 4-9). Another opportunity for hay is for feeding to cattle during live export, which could be integrated into an existing beef enterprise to supply their own live export livestock; this would require the hay to be pelleted. Section 4.3.9 considers how forages could be integrated into local beef productions systems for direct consumption by livestock within the same enterprise.

Table 4-9 Sensitivity of forage (Rhodes grass) crop gross margins ($/ha) to variation in yield and hay price

The base case is the Gregory heavy Vertosol (Table 4-6) and is highlighted for comparison. Transporting the hay further distances would increase opportunities for finding counter-seasonal markets paying higher prices, but this would be rapidly offset by higher freight costs.

FREIGHT COST/TONNE (DISTANCE TO DELIVER)	FORAGE CROP GROSS MARGIN ($/ha)		
	HAY PRICE/TONNE		
	$150	$250	$350
$20 (local)	317	3530	9495
$92 (330 km to Cloncurry)	–1708	1505	7471
$243 (1250 km to Emerald)	–9917	–6704	–738

4.3.6 Irrigated horticultural crops

Table 4-10 shows estimates of potential performance for a range of horticultural crop options in the Southern Gulf catchments. Upper potential GMs for annual and tree horticulture are about $5000 per ha per year). Capital costs of farm establishment and operating costs increase as the intensity of farming increases, so ultimate farm financial viability is not necessarily better for horticulture compared to broadacre crops with lower GMs (see Chapter 6). Note also that perennial horticulture crops typically require more water than annual crops because irrigation occurs for a longer period each year (mean of 8.5 compared to 4.4 ML per ha per year, respectively in Table 4-10); this also, indirectly, affects capital costs of development since perennial crops require a larger investment in water infrastructure compared to annual crops to support the same cropped area.

Table 4-10 Performance metrics for horticulture options in the Southern Gulf catchments: annual applied irrigation water, crop yield and gross margin

Applied irrigation water includes losses of water during application. Horticulture is most likely to occur on well-drained Kandosols. Product unit prices listed are for the dominant top grade of produce, but total yield was apportioned among lower graded/priced categories of produce as well in calculating total income. Transport costs assume sales of total produce are split among southern capital markets in proportion to their size. Applied irrigation water accounts for application losses assuming efficient pressurised micro irrigation systems. KP = Kensington Pride mangoes; PVR = new high-yielding mangoes varieties with plant variety rights (e.g. Calypso).

CROP	APPLIED IRRIGATION WATER (ML/ha/y)	CROP YIELD (t/ha/y)	PRICE ($/unit)	PRICING UNIT (unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)
Row crop fruit and vegetables, annual horticulture (less capital intensive)							
Rockmelon	5.0	25.0	28	15 kg tray	43,216	44,000	784
Watermelon	5.7	47.0	450	500 kg box	52,321	42,300	–10,021
Capsicum	3.0	32.0	19	8 kg carton	71,158	76,000	8,842
Onion	4.0	30.0	15	10 kg bag	36,906	41,850	4,944
Fruit trees, perennial horticulture (more capital intensive)							
Mango (KP)	7.4	9.3	24	7 kg tray	22,023	28,398	6,375
Mango (PVR)	7.4	17.5	21	7 kg tray	42,786	47,250	4,464
Lime	10.8	28.5	18	5 kg carton	94,913	100,890	5,977

Crop yields and GMs can vary substantially among varieties, as is demonstrated in Table 4-10 for mangoes (*Mangifera indica*). Mango production is well established in multiple regions of northern Australia, including in the Darwin, Douglas–Daly and Katherine regions of the NT, Bowen, the lower Burdekin and the Mareeba–Dimbulah Irrigation Area in Queensland. For example, the well-established Kensington Pride mangoes typically produce 5 to 10 t/ha while newer varieties (such as Calypso) can produce 15 to 20 t/ha. New varieties are likely to be released with plant variety rights (PVR) accreditation and are denoted as such. Selection of varieties also needs to consider consumer preferences and timing of harvest relative to seasonal gaps in market supply that can offer premium prices.

Prices paid for fresh fruit and vegetables can be extremely volatile (Figure 4-9) because produce is perishable and expensive to store, and because regional weather patterns can disrupt target timing of supply, which can result in unintended overlaps or gaps in combined supply between regions. This creates regular fluctuations between oversupply and undersupply, against inelastic consumer demand, to the extent that prices can fall so low at times that it would cost more to pick, pack and transport produce than farms receive in payment. Within this volatility are some counter-seasonal windows in southern markets (where prices are typically higher) that northern Australian growers can target.

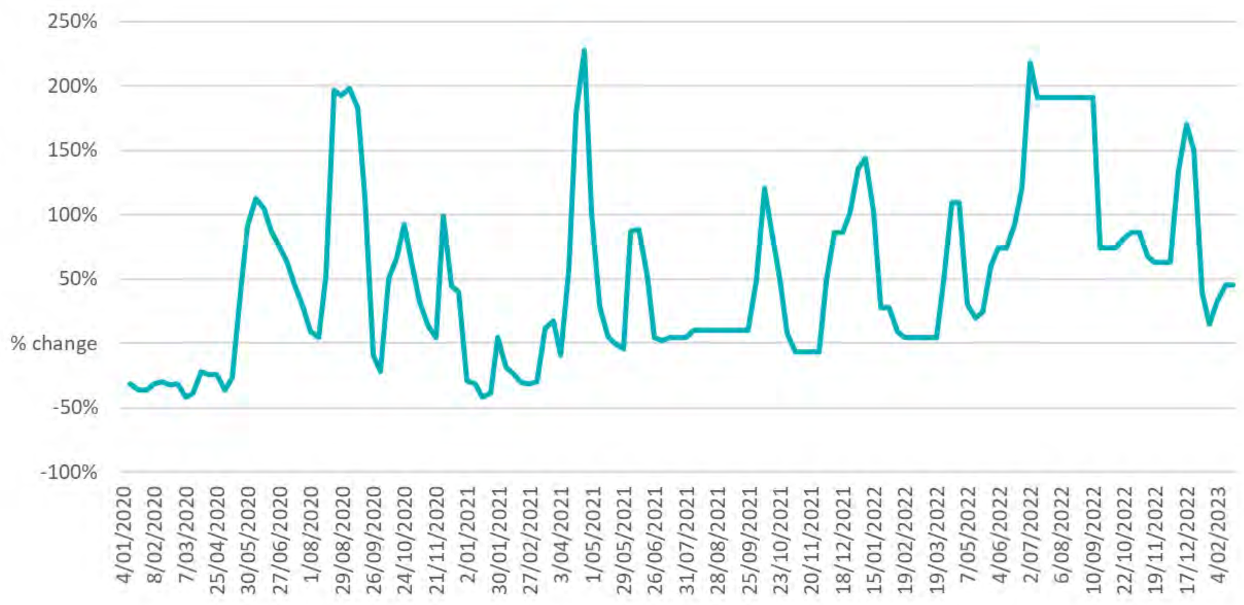

Figure 4-9 Fluctuations in seedless watermelon prices at Melbourne wholesale markets from April 2020 to February 2023

Percentage change information available; however, prices are commercially sensitive and not available.

Source: ABARES (2023)

Horticultural enterprises typically run on very narrow margins, where about 90% of gross revenue would be required just to cover variable costs of growing and marketing a crop grown in the Southern Gulf catchments. This makes crop GMs extremely sensitive to fluctuations in variable costs, yield and produce prices, amplifying the effect of already volatile prices for fresh fruit and vegetables. The majority of the variable costs of horticultural production occur from harvest onwards, mainly in freight, labour and packaging. This affords the opportunity to mitigate losses if market conditions are unfavourable at the time of harvest, since most costs can be avoided (at the expense of foregone revenue) by not picking the crop.

The narrative risk analysis for horticulture used the crop with the lowest GM (watermelons (*Citrullus lanatus*) Table 4-10, to illustrate how opportunities for reducing freight costs and targeting periods of higher produce prices could improve GMs to find niches for profitable farms (Table 4-11). Reducing freight costs by finding backloading opportunities or concentrating on just the smaller closest southern capital city market of Brisbane would substantially improve GMs, but a higher price than average is needed to generate positive GMs. The base case already assumed that growers in the Southern Gulf catchments would target the predictable seasonal component of watermelon price fluctuations (Figure 4-9), but any further opportunity to attain premiums in pricing could help convert an unprofitable baseline case into a profitable one. This example also highlights the issue that while there may be niche opportunities that allow an otherwise unprofitable enterprise to be viable, the scale of those niche opportunities also then limits the scale to which the industry in that location could expand; for example: (i) there is a limit to the volume of backloading capacity at cheaper rates, (ii) supplying produce to only the closest market excludes the largest markets (e.g. accessing the larger Sydney and Melbourne markets remains non-viable except when prices are high; Table 4-11) and (iii) chasing price premiums restricts the seasonal windows into which produce is sold or restricts markets to smaller niches that target specialised product specifications. Niche opportunities are seldom scalable, particularly in horticulture, which is partly why horticulture in any region usually involves a range of different crops (often on the same farm).

Table 4-11 Sensitivity of watermelon crop gross margins ($/ha) to variation in melon prices and freight costs
The base case (Table 4-10) is highlighted for comparison.

FREIGHT COST/TONNE (MARKET LOCATION)	WATERMELON PRICE (PERCENTAGE DIFFERENCE FROM BASE PRICE)			
$210/t	$337 (–25%)	$450 (BASE PRICE)	$675 (+50%)	$900 (+100%)
$342 (backloading to Brisbane)	–10,836	–1,702	16,487	34,676
$429 (close market: Brisbane)	–14,925	–5,791	12,398	30,587
$519 (all capital cities)	–19,155	–10,021	8,168	26,357
$559 (Melbourne)	–21,035	–11,901	6,288	24,477

The risk analysis also illustrates just how much farm financial metrics like GMs amplify fluctuations to input costs and commodity prices to which they are exposed. For horticulture, far more than broadacre agriculture, it is very misleading to look just at a single ‘median’ GM for the crop, because that is a poor reflection of what is going on within an enterprise. For example, a –50% to +100% variation in watermelon prices would result in theoretical annual GMs fluctuating between –$19.155/ha and $26,357/ha (Table 4-11). Although, in practice, potentially negative GMs could be greatly mitigated (by not harvesting the crop), this still creates cashflow challenges in managing years of negative returns between years of windfall profits. This amplified volatility is another reason that horticultural farms often grow a mix of produce (as a means of spreading risk). For row crop production, another common way of mitigating risk is using staggered planting through the season, so that subsequent harvesting and marketing are spread out over a longer target window to smooth out some of the price volatility.

4.3.7 Plantation tree crops

Estimates of annual performance for African mahogany (*Khaya ivorensis*) are provided in Table 4-12. The best available estimates were used in the analyses, but information on plantation tree production in northern Australia is often commercially sensitive and/or not independently verified. The measures of performance presented, therefore, have a low degree of confidence and should be treated as broadly indicative, noting that actual commercial performance could be either lower or higher.

Table 4-12 Performance metrics for plantation tree crop options in the Southern Gulf catchments: annual applied irrigation water, crop yield and gross margin

Yields are values at final harvest and pricing unit is for an 800 kg cube, with 10% of the African mahogany yield as marketable cubes. Other values are annual averages assuming a 20-year life cycle of the crop (representing the idealised ultimate steady state of an operating farm that was set up with staggered plantings for a steady stream of harvests). No discounting is applied to account for the substantial timing offset between when costs are incurred and revenue is received; any investment decision would need to take that into account. African mahogany performance is for unirrigated production.

CROP	CROP LIFE CYCLE	APPLIED IRRIGATION WATER	CROP YIELD AT HARVEST	PRICE	PRICING UNIT	VARIABLE COSTS	TOTAL REVENUE	GROSS MARGIN
	(y)	(ML/ha/y)	(t/ha)	($/unit)		($/ha/y)	($/ha/y)	($/ha/y)
African mahogany	20	unirrigated	160	4000	cube	1103	4000	2897

Plantation forestry has long life cycles with low-intensity management during most of the growth cycle, so variable costs typically consume less of the gross revenue (28%) than for broadacre or horticultural farming. However, production systems with long life cycles have additional risks over annual cropping: there is a much longer period between planting and harvest for adverse events to affect the yield quantity and/or quality, prices of inputs and harvested products could change substantially over that period, and market access and arrangements with buyers could change. The long lags from planting to harvest also mean that potential investors need to consider other similar competing pipeline developments (that may not be obvious because they are not yet selling product) and long-term future projections of supply and demand (for when their own plantation will start to be harvested and enter supply chains). The cashflow challenges are also significant given the long-term outlay of capital and operating costs before any revenue is generated. Carbon and other externality credits might be able to assist with some early cashflow (e.g. if the ‘average’ state of the plantation, from planting to harvest, stores more carbon than the vegetation it replaced).

4.3.8 Cropping systems

This section evaluates the types of cropping systems (crop species × growing season × resource availability × management options) that are most likely to be profitable in the Southern Gulf catchments based on the above analyses of GMs, information from companion technical reports in this Assessment, and cropping knowledge from climate-analogous regions (relative to local biophysical conditions). Cropping system choices could include growing a single crop during a 12-month period, or growing more than one crop – commonly referred to as sequential, double or rotational cropping. Since many of the issues for single cropping options were covered earlier, this section focuses on sequential cropping systems and the mix of cropping options that might be grown in sequence on a unit of land in the Southern Gulf catchments.

Cropping system considerations

Selecting two or more crops to grow in sequence increases the complexity, beyond the issues already discussed, in finding and adapting individual cropping options for the Southern Gulf catchments. The rewards from successfully growing crops in sequence (versus single cropping) can be substantial if additional net annual revenue can be generated from the same initial capital investment (to establish the farm). To find viable mixes of cropping options for the Southern Gulf catchments, developers will need to consider each of the following four key factors.

Markets

Whether growing a single crop or doing sequential cropping, the choice of crop(s) to grow is market driven. As the price received for different crops fluctuates, so too will the crops grown. In the Southern Gulf catchments, freight costs, determined by the distance to selected markets, must also be considered. A critical scale of production may be needed for a new market opportunity or supply chain to be viable (e.g. exporting grains from Townsville would require sufficient economies of scale for the required supporting port infrastructure, and shipping routes to be viable). Crops such as cotton, peanut and sugarcane (*Saccharum officinarum*) require a processing facility. A consistent and critical scale of production is required for processing facilities to be viable. Transport costs of raw cotton from the Southern Gulf catchments to the closest gin in Emerald would be offset by access to a gin locally and go a long way to improving the viability of cotton production (Table 4-8).

Most horticultural production from the Southern Gulf catchments would be sent to capital city markets, often using refrigerated transport. Horticultural production in the Southern Gulf catchments would have to accept a high freight cost compared to the costs faced by producers in southern parts of Australia. The competitive advantage of horticultural production in the Southern Gulf catchments is that higher market prices can be achieved from 'out-of-season' production compared to large horticultural production areas in southern Australia. Annual horticultural row crops, such as melons, would be grown sequentially, for example with fortnightly planting over 3 to 4 months, to reduce risk of exposure to low market prices and to make it more likely that very high market prices would be achieved for at least some of the produce.

Operations

Sequential cropping can require a trade-off against sowing at optimal times to allow crops to be grown in a back-to-back schedule. This trade-off could lead to lower yields from planting at suboptimal times. For annual horticultural crops there would be additional trade-offs in the seasonal window over which produce can be sent to market (affecting opportunities to target seasonal peaks in prices and to use staggered planting dates to mitigate risks from price fluctuations).

Growing crops sequentially depends on timely transitions between the crops, and selecting crops that are agronomically and operationally compatible with each other, including growing seasons that reliably fit together in the available cropping windows. In the catchments' variable and often intense wet season, rainfall increases operational risk because of reduced trafficability and the subsequent limited ability to conduct timely operations. A large investment in machinery (either multiple or larger machines) could increase the area that could be planted per day when fields are trafficable within a planting window. With sequential cropping, additional farm machinery and equipment may be required where there are crop-specific machinery requirements, or to help complete operations on time when there is tight scheduling between crops. Any additional capital expenditure on farm equipment would need to be balanced against the extra net farm revenue generated.

Sequential cropping can also lead to a range of cumulative issues that need careful management, for example: (i) build-up of pests, diseases (particularly if the sequential cropping is of the same species or family) and weeds; (ii) pesticide resistance; (iii) increased watertable depth; and (iv) soil chemical and structural decline. Many of these challenges can be anticipated before beginning sequential cropping. Integrated pest, weed and disease management would be essential when multiple crop species are grown in close proximity (adjacent fields or farms). Many of these pests and controls are common to several crop species where pests (e.g. aphids) move between fields. Such situations are exacerbated when the growing seasons of nearby crops partially overlap or when sequential crops are grown, because both scenarios create 'green bridges' that facilitate the continuation of pest life cycles. When herbicides are required, it is critical to avoid products that could damage a susceptible crop the following season or sequentially.

Water

Sequential cropping leads to a higher annual crop water demand (versus single cropping) because: (i) the combined period of cropping is longer, (ii) it includes growing during the dry season in the Southern Gulf catchments and (iii) PAW at planting will have been depleted by the previous crop. Typically, an additional 1 ML/ha on well-drained soils, and 1.5 ML/ha on clays, is required for sequential cropping relative to the combined water requirements of growing each of those crops individually (with the same sowing times). This additional water demand needs to be accounted for in initial farm planning, particularly where on-farm water storage or dry-season water extraction is required.

Irrigating using surface water in the Southern Gulf catchments would face issues with the reliability and the timing of water supplies. Monitored river flows need to be sufficient to allow pumping into on-farm storages for irrigation (i.e. to meet environmental flow and river height requirements). The timing of water availability is analysed in the companion technical report on river model scenario analysis (Gibbs et al., 2024). The availability of water for extraction each wet season affects the options for sequencing a second crop.

Soils

The largest arable areas in the Southern Gulf catchments are the cracking clay Vertosols (SGG 9, marked 'A' and 'D' in Figure 4-3), principally on the floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland. Friable, non-cracking clay soils (SGG 1 and 2, marked 'B' and 'C') and loamy soils (SGG 4, marked 'F') make up substantial areas (Figure 4-3). There are good analogues of these environments in the Southern Gulf catchments in successful irrigated farming areas in other parts of northern Australia. Katherine is indicative of farming systems and potential crops grown on well-drained loamy soils irrigated by pressurised systems, and the Burdekin River Irrigation Area and Ord River Irrigation Area are indicative of furrow irrigation on heavy clay soils.

The good wet-season trafficability of the well-drained loamy Kandosols permits timely cropping operations and would enhance the implementation of sequential cropping systems. However, Kandosols also present some constraints for farming. Kandosols are inherently low in organic carbon, nitrogen, potassium, phosphorus, sulfur and zinc, and supplementation with other micronutrients (boron, copper and molybdenum) is often required. Very high fertiliser inputs are therefore required at first cultivation. Due to the high risk of leaching of soluble nutrients (e.g. nitrogen and sulfur) during the wet season, in-crop application (multiple times) of the majority of crop requirement for these nutrients is necessary (Yeates, 2001). In addition, high soil temperatures and surface crusting combined with rapid drying of the soil at seed depth reduce crop establishment and seedling vigour for many broadacre species sown during the wet season and early dry season, for example, maize, soybean (*Glycine max*) and cotton (Abrecht and Bristow, 1996; Arndt et al., 1963).

In contrast, the cracking clay Vertosols have poor trafficability following rainfall (Figure 4-6) inundation or irrigation, disrupting cropping operations. Farm design is a major factor on cracking clay soils and needs to minimise flooding of fields from nearby waterways, ensure prompt runoff from fields after irrigation or rain events, and ensure that farm roads maintain access to fields. Timely in-field bed preparation can reduce delays in planting. Clay soils also have some advantages, particularly in costs of farm development by allowing lower-cost gravity-fed surface irrigation (versus pressurised systems) and on-farm storages (where expensive dam lining can be avoided if soils contain sufficient clay) (see companion technical report on surface water storage, Yang et al., 2024). Clay soils also typically have greater inherent fertility than loamy soils, but initial sorption by clay means that phosphorus requirements can be high for virgin soils in the first 2 years of farming.

Potentially suitable cropping systems

Potential crop species that could be grown as a single crop per year were identified and rated for the Southern Gulf catchments (Table 4-13) based on indicators of farm performance presented above (yields, water use and GMs), together with considerations of growing season, experiences at climate-analogous locations, past research, and known market and resource limitations and opportunities. Many of these crops currently have small to medium high-value markets, hence they are sensitive to Australian and international supply. Annual horticulture, cotton, peanut and forages are the most likely to generate returns that could exceed farm development and growing costs (Table 4-13).

Table 4-13 Likely annual irrigated crop planting windows, suitability and viability in the Southern Gulf catchments

Crops are rated on likelihood of being financially viable: *** = likely at low-enough development costs; ** = less likely for single cropping (at current produce prices); * ^{S} = marginal but possible in a sequential cropping system. Rating qualifiers are coded as ^{L} development limitation, ^{M} market constraint, ^{P} depends on sufficient scale and distance to local processor, and ^{B} depends on distance to and type of beef (livestock production) activity it is supporting. Farm viability depends on the cost at which land and water can be developed and supplied (Chapter 6). na = not applicable.

WET-SEASON PLANTING (JANUARY TO EARLY MAY)		DRY-SEASON PLANTING (LATE MARCH TO AUGUST)	
CROP	RATING	CROP	RATING
Cotton	*** ^{P}	**Annual horticulture**	*** ^{M}
Forages	*** ^{B}	**Cotton**	*** ^{P}
Sugarcane	*** ^{LP}	**Niche grains (e.g. chia, quinoa)**	*** ^{SM}
Peanut (not on clay)	*** ^{LMP}	na	na
Mungbean	**	**Mungbean**	**
Maize	**	na	na
Chickpea	**	na	na
Rice	** ^{L}	na	na
Sorghum (grain)	* ^{S}	**Sorghum (grain)**	* ^{S}
Soybean	* ^{S}	**Soybean**	* ^{S}
Sesame	* ^{S}	**Sesame**	* ^{S}

Due to good wet-season trafficability on loamy soils, there are many sequential cropping options for the Southern Gulf catchments Kandosols (Table 4-14). Given the predominance of broadleaf and legume species in many of the sequences (Table 4-14), a grass species is desirable as an early wet-season cover crop. Although annual horticulture and cotton could individually be profitable (Table 4-13), an annual sequence of the two would be very tight operationally. Cotton would be best grown from late January with the need to pick the crop by early August, then destroy cotton stubble, prepare land and remove volunteer cotton seedlings. That scheduling would make it challenging to fit in a late-season melon crop, which would need to be sown by late August to early September. Similar challenges would occur with cotton followed by mungbean or grain sorghum.

Table 4-14 Sequential cropping options for Kandosols

	WET-SEASON PLANTING, DECEMBER TO EARLY MARCH		DRY-SEASON PLANTING, MARCH TO AUGUST
CROP	GROWING SEASON	CROP	GROWING SEASON
Mungbean **Sorghum (grain)** **Peanut (not on clay)**	Early February to late April January to April January to April or February to May	**Annual horticulture**	Mid-May to late October
Cotton	Late January to early August	**Mungbean** **Sorghum (grain)** **Forage/silage**	Mid-August to late October Mid-August to mid-November Mid-August to early November; cut then retained as wet-season cover crop
Mungbean	Early February to late April	**Cotton**	Early May to early November
Mungbean **Peanut** **Sesame** **Soybean**	Early February to late April Early January to late April Early January to late April Early January to late April	**Maize**	May to October
Sesame or **Sorghum (grain)**	January to late April	**Chickpea**	May to August
Mungbean **Sesame** **Soybean**	Early February to late April January to late April January to late April	**Grass forage/silage**	May to early November; cut then retained as wet-season cover crop

Fully irrigated sequential cropping on the Southern Gulf catchments Vertosols would likely be opportunistic and favour combinations of short-duration crops that can be grown when irrigation water reliability is greatest (March to October), for example, annual horticulture (melons), mungbean, chickpea and grass forages (growing season 2 to 4 months). Following an unirrigated (rainfed) wet-season grain crop with an irrigated dry-season crop could also be possible. However, seasonally dependent soil wetting and drying would limit timely planting and the area planted, which means that farm yields between years would be very variable. Sorghum (grain), mungbean and sesame (*Sesamum indicum*) are the species most adapted to rainfed cropping due to favourable growing season length, and their tolerance to water stress, and higher soil and air temperatures. Soil drainage, accessibility and trafficability would limit the scale of farming in the wet season within the Southern Gulf catchments (which would restrict opportunities for establishing local processors).

4.3.9 Integrating forage and hay crops into existing beef cattle enterprises

A commonly held view within the northern cattle industry is that the development of water resources would allow irrigated forages and hay to be integrated into existing beef cattle enterprises, thereby improving their production and, potentially, their profitability. Currently, cattle graze on native pastures, which rely solely on rainfall and any consequent overland flow. The quality of these pastures is typically low, and it declines throughout the dry season, so that cattle either gain little weight, or even lose weight, during this period.

Theoretically, the use of on-farm irrigated forage and hay production would allow graziers greater options for marketing cattle, such as meeting market liveweight specifications for cattle at a younger age, meeting the specifications required for markets different than those typically targeted by cattle enterprises in the Southern Gulf catchments and providing cattle that meet market specification at a different time of the year. Forages and hay may also allow graziers to implement management strategies, such as early weaning or weaner feeding, which should lead to flow-on benefits throughout the herd, including increased reproductive rates. Some of these strategies are already practised within the Southern Gulf catchments but in almost all incidences are reliant on hay or other supplements purchased on the open market. By growing hay on-farm, the scale of these management interventions might be increased, at reduced net cost. Furthermore, the addition of irrigated feeds may allow graziers to increase the total number of cattle that can be sustainably carried on a property.

Very few cattle enterprises in northern Australia are set up to integrate on-farm irrigation, notwithstanding the theoretical benefits. Despite its apparent simplicity, fundamentally altering an existing cattle enterprise in this way brings in considerable complexity, with a range of unknowns about how best to increase productivity and profitability. The most comprehensive guide to what might be possible to achieve by integrating forages into cattle enterprises can be found in the guide by Moore et al. (2021), who have used a combination of industry knowledge, new research and modelling to consider the costs, returns and benefits. Because there are so few on-ground examples, modelling has been used in a number of studies to consider the integration of forages and hay into cattle enterprises, summarised by Watson et al. (2021).

Bio-economic modelling was used in the Assessment to consider the impact of growing irrigated forages and hay on a representative beef cattle enterprise on the cracking clays of the 'Bluegrass Browntop Plains' land type (Southern Gulf NRM, 2016) (see the companion technical report on agricultural viability and socio-economics (Webster et al., 2024) for more detail). The enterprise was based on a self-replacing cow–calf operation, focused on selling into the live export market. Broadly speaking, these enterprise characteristics can be thought of as an owner–manager small cattle enterprise within the Southern Gulf catchments. Cattle numbers are lower than that of the average property in the Southern Gulf catchments but can be scaled to represent larger herds, notwithstanding that economies of scale will result in reduced costs per head in the larger enterprises. More detail on the beef industry in the Southern Gulf catchments can be found in Section 3.3.3.

The modelling considered a number of management options: (i) a base enterprise; (ii) base enterprise plus buying in hay to feed weaners; growing forage sorghum, an annual forage grass species, and feeding either as (iii) stand and graze or (iv) as hay; (v) growing lablab (*Lablab purpureus*), an annual legume, and feeding as stand and graze; and (vi) growing Rhodes grass, a perennial tropical grass, and feeding as hay.

Ideally, production would increase by allowing cattle to reach minimum selling weight at a younger age and allowing for greater weight gain during the dry season when animals on native pasture alone either lose weight or gain very little weight. The addition of forages and hay also allows more cattle to be carried, while still maintaining a utilisation rate of native pastures at around 18%.

A GM per adult equivalent (AE) was calculated as the total revenue from cattle sales minus total variable costs (Table 4-15). A profit metric, earnings before interest, taxes, depreciation and amortisation (EBITDA), was also calculated as income minus variable and overhead costs, which allows performance to be compared independently of financing and ownership structure (McLean and Holmes, 2015) and is used in the analysis of NPV. Three sets of beef prices were considered:

- LOW beef price. Beef prices were set to 275c/kg for males between 12 and 24 months old, declining across age and sex classes to 134c/kg for cows older than 108 months.
- MED beef price. Beef prices were set to 350c/kg for males between 12 and 24 months old, declining across age and sex classes to 170c/kg for cows older than 108 months.
- HIGH beef price. Beef prices were set to 425c/kg for males between 12 and 24 months old, declining across age and sex classes to 206c/kg for cows older than 108 months.

At all three beef prices, total income was highest for the four irrigated forage or hay scenarios compared to the two baseline scenarios.

At MED beef prices, EBITDA was highest for the Rhodes grass hay option at $160,929/year and lowest for forage sorghum stand and graze at –$232,238/year. The Rhodes grass hay option and the forage sorghum hay option produced the most liveweight sold per year, and the two highest incomes.

An NPV analysis allows consideration of the capital costs involved in development, which are not captured in the gross margin or EBITDA. The analysis used two costings ($15,000 and $25,000/ha) for the capital costs of development used in the NPV analysis. The NPV analysis (see the companion technical report on agricultural viability and socio-economics (Webster et al., 2024)) showed that only two irrigated combinations had a positive NPV, that of Rhodes grass hay at MED and HIGH beef prices and the lower of the two development costs per hectare. All other combinations gave a negative NPV and even the two positive NPVs were low ($18,444 and $114,386), suggesting that a decision to irrigate would need to assume beef prices remaining strong to be viable. Note that cost of capital theory is complex and investors need to understand their weighted average cost of capital and the relative risk of the project compared to the enterprise’s existing project portfolio before drawing their own conclusion from an NPV analysis.

Table 4-15 Production and financial outcomes from the different irrigated forage and beef production options for a representative property in the Southern Gulf catchments

Details for LOW, MED and HIGH beef prices are in the text above. Descriptions of the six management options are in the companion technical report on agricultural viability and socio-economics (Webster et al., 2024). AE = adult equivalent; EBITDA = earnings before interest, taxes, depreciation and amortisation. Cattle are sold twice per year for all options. Cattle are sold in May for all options. Cattle are sold in September for the two base enterprises and for lablab stand and graze. Cattle are sold in October for forage sorghum stand and graze and the two hay options.

	BASE ENTERPRISE	BASE ENTERPRISE PLUS HAY	FORAGE SORGHUM – STAND AND GRAZE	FORAGE SORGHUM – HAY	LABLAB – STAND AND GRAZE	RHODES GRASS – HAY
Forage/hay	None	Bought hay	Forage sorghum	Forage sorghum	Lablab	Rhodes grass
Maximum number of breeders	1580	1600	1705	1800	1730	1800
Mean of herd size (AE) across calendar year	1841	1867	2107	2182	2138	2188
Pasture utilisation (%)	18.1	18.2	17.9	18.2	18.1	18.0
Weaning rate (%)	55.5	55.4	55.9	57.6	58.4	58.9
Mortality rate (%)	7.0	7.0	6.7	6.3	6.3	6.4
Percentage of 'one year old castrate males' (i.e. 7 to 11 months or 8 to 12 months old) sold in September or October	0.0	0.0	0.5	77.5	57.9	77.9
Percentage of 'one and a half year old castrate males' (i.e. 15 to 19 months old) sold in May	48.3	60.5	73.2	17.8	25.2	17.8
Percentage of 'two year old castrate males' (i.e. 19 to 23 months or 20 to 24 months old) sold in September or October	11.2	11.0	25.0	4.7	16.9	4.2
Percentage of 'two and a half year old castrate males' (i.e. 27 to 31 months old) sold in May	40.5	28.6	1.3	0.0	0.0	0.0
Liveweight sold per year (kg)	212,840	220,123	264,395	303,699	290,798	306,171
Gross margin ($/AE) (LOW beef price)	91	78	-64	103	40	129
Profit (EBITDA) ($) (LOW beef price)	–96,612	–119,279	–398,807	-40,193	–178,627	17,028
Gross margin ($/AE) (MED beef price)	163	152	15	168	123	194
Profit (EBITDA) ($) (MED beef price)	35,348	19,399	–232,238	102,546	–1,240	160,929
Gross margin ($/AE) (HIGH beef price)	236	226	94	232	205	260
Profit (EBITDA) ($) (HIGH beef price)	169,437	158,076	–65,670	242,247	173,239	304,829

A significant proportion of the animal production increases due to the irrigated forage options came from the increased number of breeders that could be carried, and the decreased number of young animals being carried over an additional wet season in order to achieve sale weight, while still keeping the utilisation rate of native pastures close to 18% (Table 4-15). The two irrigated hay options allowed the highest number of breeders to be carried (1800) compared with 1580 and 1600 for the two base enterprises. This flowed through to the total number of AE carried being about 17% to 19% higher than the two base enterprises averaged across all years. The total liveweight sold each year was about 38% to 44% higher, using the same comparison of options due to the higher liveweight gains from the feeding options combined with the higher AE. The irrigated options increased the herd's weaning rate by 0.4% to 3.4% compared to the base enterprise without weaner feeding. Even an increase of several per cent is known to have lifetime benefits throughout a herd.

The most obvious biophysical impact of the various feeding strategies was the increase in liveweight compared to that of the base enterprise. This allowed a greater proportion of the animals to be sold earlier. For example, for the two hay options, more than 77% of the 'one-year-old castrate males' (8–12 months old) were sold in October at a minimum weight of 280 kg, while no animals from the same cohort under the two base enterprise options met the minimum weight at that time (Table 4-15). These latter animals were retained for an additional wet season, with 48.3% (base enterprise) or 60.3% (base enterprise plus hay) being sold in the following May as 'one-and-a-half-year olds' (15 to 19 months old). Keeping the utilisation rate at 18.0% meant that carrying these animals for the extra period lowered the number of breeders that could be carried, and the overall stocking rate (AE).

In summary, three patterns of growth to reach sale weight (280 kg) occurred:

- For the two base enterprises, no animals reached sale weight in September as 'one-year olds'. By the following May 48.3% (base enterprise) or 60.5% (base enterprise plus hay) had reached sale weight. About 11% were sold in the next September as 'two-year olds'. The remaining 40.5% (base enterprise) or 28.6% (base enterprise plus hay) were then sold in the following May as 'two-and-a-half-year olds'.
- By contrast, the majority of animals in the forage sorghum hay, lablab stand and graze, and Rhodes grass hay options were sold as 'one-year olds' in October. The majority of the rest (17.8%, 25.2% and 17.8%, respectively) were sold in the following May. The remainder were sold in the next October. None of this cohort remained for sale in the following May as 'two-and-a-half-year olds'.
- The forage sorghum graze option sat between these two extremes. Very few were sold as 'one-year olds' in October, most were sold as 'one-and-a-half-year olds' in the following May with almost all of the remainder sold in the following September. Only 1.3% remained to be sold as 'two-and-a-half-year olds' in the following May.

While there are advantages to some form of irrigated forage or hay production, the introduction of irrigation to an existing cattle enterprise is not for the faint-hearted. The options here range from an area that would require 1.6 pivots of 40 ha each to an area that would require more than five 40 ha pivots. A water allocation of about 1.1 to 2.1 GL would be required to provide sufficient irrigation water. The capital cost of development would range between $975,000 for 65 ha of Rhodes grass hay, at a development cost of $15,000/ha, to $5,125,000 for 205 ha of forage sorghum stand and graze at a development cost of $25,000/ha. In addition, the grazing enterprise would need to develop the expertise and knowledge required to run a successful irrigation enterprise of that scale, which is quite a different enterprise to one of grazing only. This is a constraint recognised by graziers elsewhere in northern Australia (McKellar et al., 2015) and almost certainly contributes to the lack of uptake of irrigation in the Southern Gulf catchments.

4.4 Crop synopses

4.4.1 Introduction

The estimates for land suitability in these synopses represent the total areas of the catchments unconstrained by factors such as water availability, landscape complexity, land tenure, environmental and other legislation and regulations, and a range of biophysical risks such as cyclones, flooding and secondary salinisation. These are addressed elsewhere by the Assessment. The land suitability maps are designed to be used predominantly at the regional scale. Farm-scale planning would require finer-scale, more localised assessment.

4.4.2 Cereal crops

Cereal production is well established in Australia. The area of land devoted to producing grass grains (e.g. wheat, barley (*Hordeum vulgare*), grain sorghum, maize, oats (*Avena sativa*), triticale (× *Triticosecale*)) each year has stayed relatively consistent at about 20 million ha over the decade from 2012–13 to 2021–22, yielding over 55 Mt with a value of $19 billion in 2021–22 (ABARES, 2022). Production of cereals greatly exceeds domestic demand, and in 2021–22 the majority (82% by value) was exported (ABARES, 2022). Significant export markets exist for wheat, barley and grain sorghum, with combined exports valued at $15 billion in 2021–22. There are additional niche export markets for grains such as maize and oats.

Among the cereals, sorghum (grain) is promising for the Southern Gulf catchments. Sorghum is grown over the summer period, coinciding with the Southern Gulf catchments wet season. Sorghum can be grown opportunistically using rainfed production, although the years in which this could be successfully done will be limited. Cereal crop production is higher and more consistent when irrigation is used.

From a land suitability perspective, cereal crops are included in Crop Group 7 (Table 4-2; Figure 4-10). Cracking clay soils (Vertosols) make up 23% of the catchments; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better

(Class 2 or Class 1) for irrigated cereal cropping (Crop Group 7; Table 4-2) using spray irrigation in the dry season. For spray irrigation in the wet season, nearly 3.1 million ha is suitable with moderate limitations (Class 3) or better. Land considered suitable with moderate limitations for furrow irrigation is limited to about 1.8 million ha in the dry season and about 780,000 ha in the wet season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy and sandy soils are too permeable. There is potential for rainfed cereal production in the wet season over an area of about 360,000 ha. From a land suitability perspective, Crop Group- 7 contains cereal crops and cotton; the latter is considered under industrial (cotton) in these crop synopses (Section 4.4.6).

The ‘winter cereals’ such as wheat and barley are not well adapted to the climate of the Southern Gulf catchments.

To grow cereal crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is often a contract operation, and in larger growing regions other activities can also be performed under contract. Because of the low relative value of cereals, good returns are made through production at a large scale. This requires machinery to be large so that operations can be completed in a timely way. Table 4-16 provides summary information relevant to the cultivation of cereals, using sorghum (grain) (Figure 4-11) as an example. The companion technical report on agricultural viability and socio-economics (Webster et al., 2024) provides greater detail for a wider range of crops.

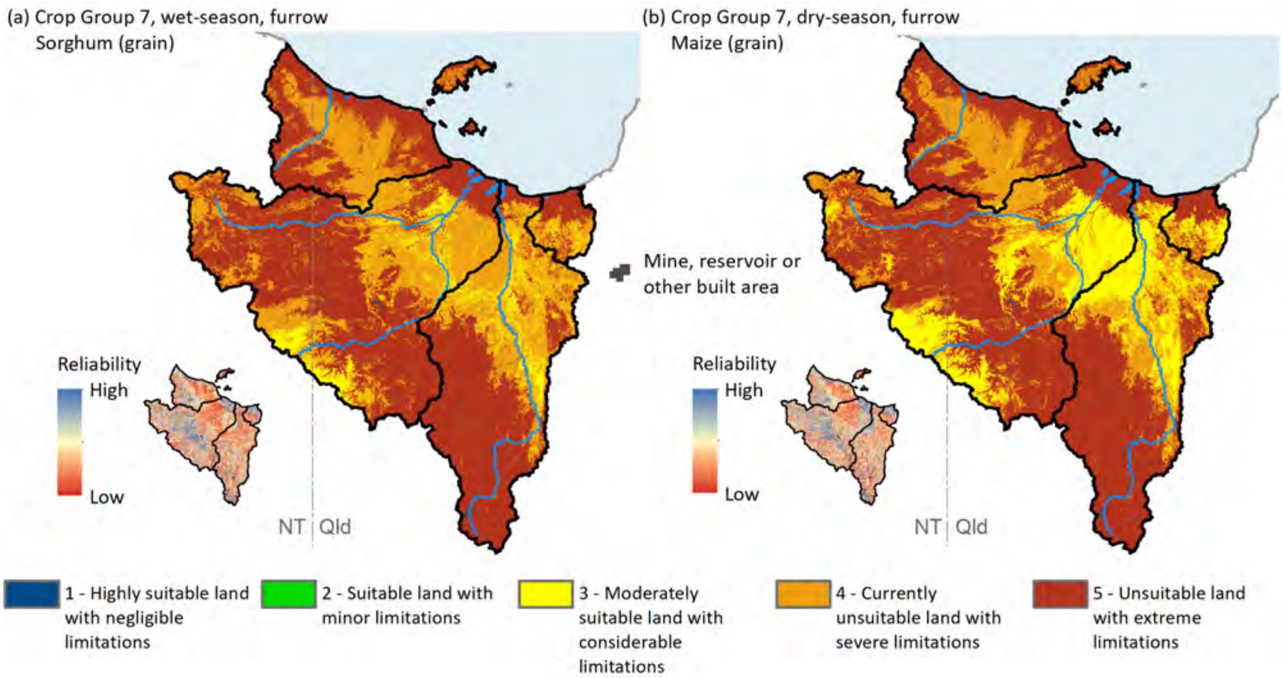

Figure 4-10 Modelled land suitability for Crop Group 7 (e.g. sorghum (grain) or maize) using furrow irrigation in the (a) wet season and (b) dry season

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Table 4-16 Summary information relevant to the cultivation of cereals, using sorghum (grain) as an example

PARAMETER	DESCRIPTION
Summary	Sorghum (grain; *Sorghum bicolor*) is a major rainfed grain crop grown mainly for stockfeed. It is currently grown extensively in Australia (200,000 to 700,000 ha/y), mainly in southern and central Queensland. Sorghum has been a grain crop grown in northern Queensland. It potentially can supply an intensification of the northern Australian cattle industry by providing grain for cattle feed.
Growing season	Planting window for both wet- and dry-season crops is January to April and May to August. Duration of growth is 110 to 140 days, depending on variety and planting date. Ranges of sorghum cultivars are available to suit different sowing times and geographic locations.
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 44% of the catchments is suitable with moderate or minor limitations under spray irrigation in the dry season, this decreases to 17% for furrow irrigation in the dry season. Wet-season spray irrigation is limited to 29% of the catchments and wet-season furrow to 7%. About 3% is considered suitable with moderate limitations for rainfed production, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface
Applied irrigation water (median)	About 6.3 ML/ha (furrow) for dry-season production
Crop yield (median)	Rainfed: 5 to 7 t/ha; irrigated: 9 to 11 t/ha
Salinity tolerance	Moderately tolerant: EC_e threshold for crop yield decline 6.8 dS/m
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stockfeed
Production risks	Heat stress at flowering, high soil temperatures for germination, grain mould
Rotations	High potential for annual rotation
Management considerations	Header, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	Medium
Markets and emerging markets	In Australia sorghum grain is used mostly for stockfeed in the cattle, pig and poultry industries. A large amount of grain is exported. Potential emerging market for feedlots supplying local abattoir
Prices	Generally $150 to $300 per t
Opportunities and risks under a changing climate	More tolerant of drought and temperature stress than maize

Figure 4-11 Sorghum (grain)
Photo: CSIRO

4.4.3 Pulse crops (food legume)

Pulse production is well established in Australia. The area of land devoted to production of pulses (mainly chickpea, lupin (*Lupinus* spp.) and field pea (*Pisum sativum*)) each year has varied from 1.1 to 2.0 million ha over the decade from 2012–13 to 2021–22, yielding over 3.8 Mt with a value of $2.5 billion in 2021–22 (ABARES, 2022). The vast majority of pulses in 2021–22 (93% by value) were exported (ABARES, 2022). Pulses produced in the Southern Gulf catchments would most likely be exported, although there is presently no cleaning or bulk handling facility nearby; however, established export ports are located at Townsville and Karumba.

Many pulse crops have a relatively short growing season, meaning they are well suited to opportunistic rainfed production, as well as irrigated production either as a single crop or in rotation with cereals or other non-legume crops. Not all pulse crops are likely to be suited to the Southern Gulf catchments. Those that are 'tender', such as field peas and beans, may not be well suited to the highly desiccating environment and periodically high temperatures. Direct field experimentation in the catchment is required to confirm this for these and other species. In the Southern Gulf catchments, mungbean and chickpea are likely to be well suited.

From a land suitability perspective, pulse crops are included in Crop Group 10 (Table 4-2; Figure 4-12). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated pulse cropping (Crop Group 10; Table 4-2) using spray irrigation in the dry season. Nearly 1.7 million ha of land is considered suitable with moderate limitations for furrow irrigation in the dry season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy soils are too permeable. There is potential for rainfed pulse production in the wet season over an area of about 360,000 ha. From a land suitability perspective, Crop Group 10 includes the pulse crops mungbean and chickpea, while soybean is considered under oilseeds in these crop synopses (Section 4.4.4).

Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, can provide nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial in reducing costs of fertiliser and associated freight. Pulses such as mungbean and chickpea can also be of high value (historical prices have reached >$1000/t), so the freight costs as a percentage of the value of the crop are lower than for cereal grains.

To grow pulse crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for pulse crops is the same as is required for cereal crops, so farmers intending on a pulse and cereal rotation would not need to purchase extra equipment.

Table 4-17 provides summary information relevant to the cultivation of many pulses using mungbean (Figure 4-13) as an example. The companion technical report on agricultural viability and socio-economics (Webster et al., 2024) provides greater detail for a wider range of crops.

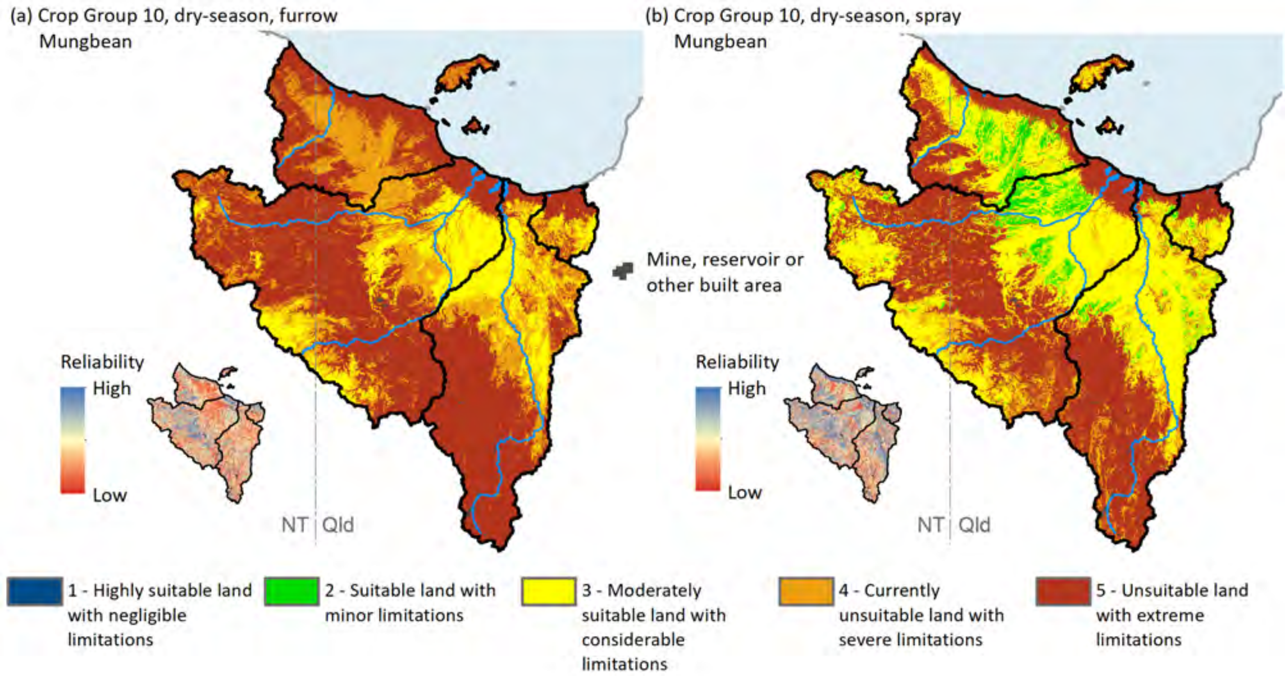

Figure 4-12 Modelled land suitability for mungbean (Crop Group 10) in the dry season using (a) furrow irrigation and (b) spray irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-13 Mungbean

Photo: CSIRO

Table 4-17 Summary information relevant to the cultivation of pulses, using mungbean as an example

PARAMETER	DESCRIPTION
Summary	Mungbean (*Vigna radiata*) is a relatively quickly maturing (90 days) grain legume that can be sown towards the end of the wet season or early dry season to avoid the hottest time of year when plants are young. Mungbean sowing will often be timed as part of a planned rotation. It is mainly used for human consumption (sprouting and processing) but can be used as green manure and livestock forage. It is currently grown mainly in northern NSW and southern Queensland. Production is generally reliable for (early) wet-season plantings for both rainfed and irrigation. There is market-driven demand for high-quality product for sprouting.
Growing season	Planting window December/January (rainfed) or February to April (wet season) or August/September (dry season)
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 44% of the catchments is suitable with moderate limitations under spray irrigation in the dry season, this decreases to 15% for furrow irrigation in the dry season. About 3% is considered suitable with moderate limitations for rainfed production in the wet season, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface
Applied irrigation water (median)	About 4.1 ML/ha (furrow)
Crop yield (median)	Rainfed: 0.9 to 1.4 t/ha; irrigated: 1.8 to 2.0 t/ha
Salinity tolerance	Sensitive: ECe threshold for crop yield decline 1.8 dS/m
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stockfeed. Nitrogen additions to soil for subsequent crops
Production risks	Rainfall during late grain fill reduces quality and price received. Insect damage can result in quality downgrades.
Rotations	Opportunity crop or annual rotation with cereals
Management considerations	Header, row crop planter, spray rig (pest control)
Complexity of management practices	Medium
Markets and emerging markets	Increasing demand for high-quality grain to supply the domestic market. Nearly all (95%) of the Australian mungbean crop is exported (Gentry, 2010).
Prices	World mungbean prices are largely determined by both the volume and quality of the crops in China and Burma. Price trends usually become obvious in December when the harvest of the Chinese crop nears completion and both the volume and quality of production become apparent. Mungbeans are classified into five grades, and price varies accordingly.
Opportunities and risks under a changing climate	Short-season opportunity crop, lower fertiliser requirements, potential for increased insect pest pressure due to increased temperatures.

4.4.4 Oilseed crops

The area of land in Australia devoted to production of oilseeds (predominantly canola, *Brassica napus*) each year has varied between 2.1 and 3.4 million ha over the decade from 2012–13 to 2021–22, yielding over 8.4 Mt with a value of $6.1 billion in 2021–22 (ABARES, 2022). The majority of oilseed produced in 2021–22 (98% by value) was exported (ABARES, 2022). Canola dominates Australian oilseed production, accounting for 98% of the gross value of oilseeds in 2021–22. Soybean, sunflower (*Helianthus annuus*) and other oilseeds (including peanuts) each accounted for less than 1%.

Soybean, canola and sunflower are oilseed crops used to produce vegetable oils and biodiesel, and high-protein meals for intensive animal production. Soybean is also used in processed foods such as tofu. It can provide both green manure and soil benefits in crop rotations, with symbiotic nitrogen fixation adding to soil fertility and sustainability in an overall cropping system. Soybean is used commonly as a rotation crop with sugarcane in northern Queensland, although often as a green manure crop. Summer oilseed crops such as soybean and sunflower are more suited to tropical environments than are winter-grown oilseed crops such as canola. Cottonseed, a by-product of cotton farming separated from the lint during ginning, is also classified as an oilseed. Cottonseed is used for animal feed and oil extraction.

Soybean is sensitive to photoperiod (day length) and requires careful consideration in selection of the appropriate variety for a particular sowing window.

From a land suitability perspective, soybean is included in Crop Group 10 (Table 4-2; Figure 4-14). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated soybean cropping (Crop Group 10; Table 4-2) using spray irrigation in the dry season. Nearly 1.7 million ha of land is considered suitable with moderate limitations for furrow irrigation in the dry season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the sandy and loamy soils are too permeable. There is potential for rainfed pulse production in the wet season over an area of about 360,000 ha. From a land suitability perspective, Crop Group 10 contains the pulse crops mungbean and chickpea, while soybean is considered under oilseeds in these crop synopses.

To grow oilseed crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation and in larger growing regions other activities can also be performed under contract. The equipment required for oilseed crops is the same as is required for cereal crops, so farmers intending on an oilseed and cereal rotation would not need to purchase oilseed-specific equipment.

With no oilseed processing facility in the north, soybean and sunflowers would need to be transported a significant distance until sufficient scales of production are achieved to justify the investment in processing facilities. Given both the modest yield and price, transport costs are likely to be a major constraint on profitability unless there is a well-developed supply chain into Asia.

Table 4-18 provides summary information relevant to the cultivation of oilseed crops using soybean (Figure 4-15) as an example. The companion technical report on agricultural viability and socio-economics (Webster et al., 2024) provides greater detail for a wider range of crops.

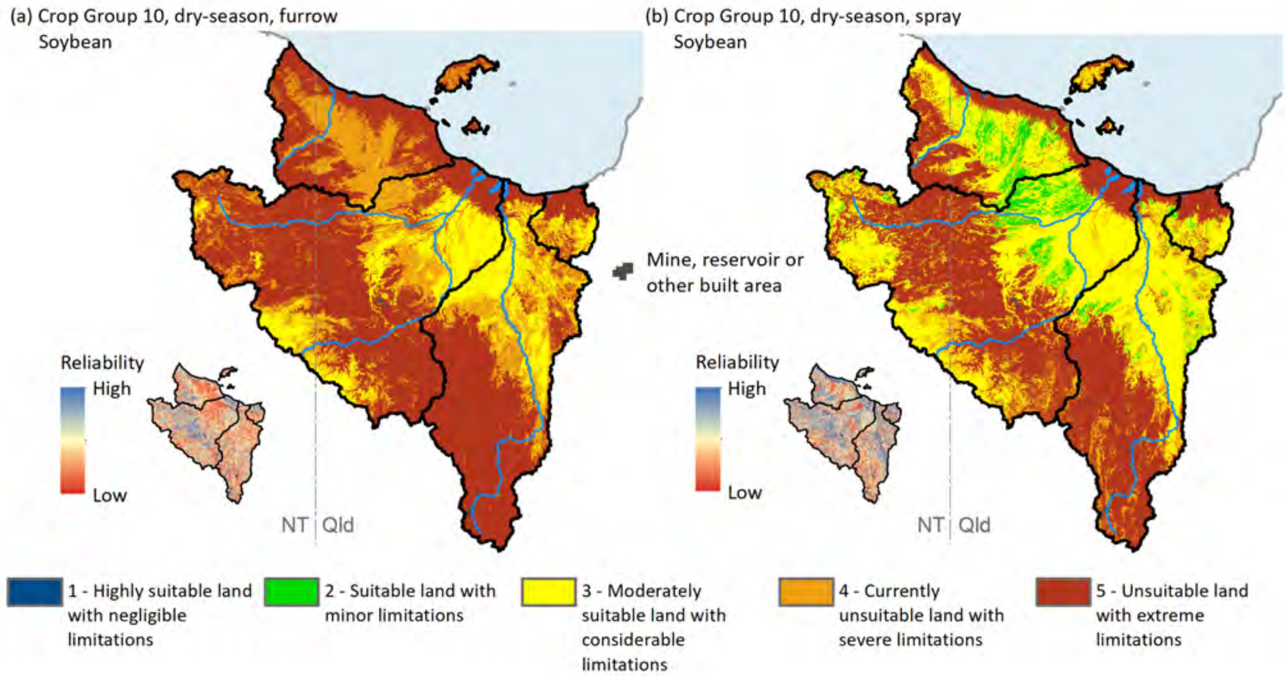

Figure 4-14 Modelled land suitability for soybean (Crop Group 10) in the dry season using (a) furrow irrigation and (b) spray irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-15 Soybean

Photo: CSIRO

Table 4-18 Summary information relevant to the cultivation of oilseed crops, using soybean as an example

PARAMETER	DESCRIPTION
Summary	Soybean (*Glycine max*) is a legume with a compact growth habit less than 1 m high. Soybean is the most widely grown oilseed crop, with many varieties available to match a wide range of Australian environments – primarily differentiated by the time taken to reach maturity. Soybeans flower as day length becomes shorter, so varieties are matched to a combination of latitude and planting time. Longer-maturing varieties are planted earlier (January) and shorter-maturing varieties can be planted later (March) to time harvest to a dryer period. Soybean is suited to a range of soil types and can be successfully grown without irrigation, relying on wet-season rain, but will yield better with irrigation. Soybean is able to tolerate moderate levels of flooding and soil salinity. It is being increasingly used as an irrigated forage and as a break crop in sugarcane production in northern Australia because of its high productivity and ease of establishment.
Growing season	Planting window is January to early April for irrigated soybean. Sowing time is matched to variety. Maturity is 100 to 130 days.
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 43% of the catchments is suitable with moderate limitations under spray irrigation in the dry season, this decreases to 15% for furrow irrigation in the dry season. About 3% is considered suitable with moderate limitations for rainfed production in the wet season, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface
Applied irrigation water (median)	About 7.9 ML/ha (furrow) for dry-season production
Crop yield (median)	Rainfed: 1 to 2.5 t/ha; irrigated: 3.5 to 5.0 t/ha
Salinity tolerance	Moderately tolerant
Downstream processing	Either sourced for edible trade (which attracts a premium) or delivered for crushing and oil extraction.
By-products	Crushed by-product is used for stockfeed. Oil has potential for use in biofuels.
Production risks	Wet conditions at harvest can be detrimental to grain quality. Wet growing conditions can also increase pest and disease pressure, requiring more control.
Rotations	Soybean is commonly used in rotations including sugarcane, cotton, rice and other crops. Soybean is a legume and therefore able to fix atmospheric nitrogen, providing a benefit to the following crop.
Management considerations	Ability to effectively use inoculants and desiccants. Direct seeders and headers. Ability to identify pests and diseases and apply effective control measures appropriately.
Complexity of management practices	Medium
Markets and emerging markets	Primarily domestic market
Prices	$450 to $750 per t
Opportunities and risks under a changing climate	Under water constraints, varieties with shorter times to maturity can be planted to conserve water.

4.4.5 Root crops, including peanut

Root crops, including peanut, sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*), are potentially well suited to the lighter soils across much of the Doomadgee Plain. Root crops such as these are not suited to growing on heavier clay soils because they need to be pulled from the ground for harvest, and the heavy clay soils, such as cracking clays, are not conducive to mechanical pulling. While peanut is technically an oilseed crop, it has been included in the root crop category due to its similar land suitability and management requirements (i.e. the need for it to be pulled from the ground as part of the harvest operation).

The most widely grown root crop in Australia, peanut is a legume crop that requires little or no nitrogen fertiliser and is very well suited to growing in rotation with cereal crops, as it is frequently able to fix atmospheric nitrogen in the soil for following crops. The Australian peanut industry currently produces approximately 15,000 to 20,000 t/year from around 11,000 ha, which is too small an industry to be reported separately in Australian Bureau of Agricultural and Resource Economics and Sciences statistics (ABARES, 2022). The Australian peanut industry is concentrated in Queensland. In northern Australia, a production area is present on the Atherton Tablelands, and peanuts could likely be grown in the Southern Gulf catchments. The Peanut Company of Australia established a peanut-growing operation at Katherine in 2007 and examined the potential of both wet- and dry-season peanut crops, mostly in rotation with maize. Due to changing priorities within the company, coupled with some agronomic challenges (Jakku et al., 2016), the company sold its land holdings in Katherine in 2012 (and Bega bought the rest of the company in 2018). For peanuts to be successful, considerable planning would be needed in determining the best season for production and practical options for crop rotations. The nearest peanut-processing facilities to the Southern Gulf catchments are at Tolga on the Atherton Tablelands and Kingaroy in southern Queensland.

From a land suitability perspective, peanut is included in Crop Group 6 (Table 4-2; Figure 4-16). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 3.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated root crops (Crop Group 6; Table 4-2) using spray irrigation in the dry season. For spray irrigation in the wet season, about 2.0 million ha is suitable with moderate limitations (Class 3) or better. Furrow irrigation was not considered in the land suitability analysis as root crops prefer lighter-textured soils too permeable for furrow irrigation.

To grow root crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. The harvesting operation requires specialised equipment to ‘pull’ the crop from the ground, and then to pick it up after a drying period. Peanuts are usually dried soon after harvest, in industrial driers.

Table 4-19 provides summary information relevant to the cultivation of root crops using peanut (Figure 4-17) as an example. The companion technical report on agricultural viability and socio-economics (Webster et al., 2024) provides greater detail for a wider range of crops.

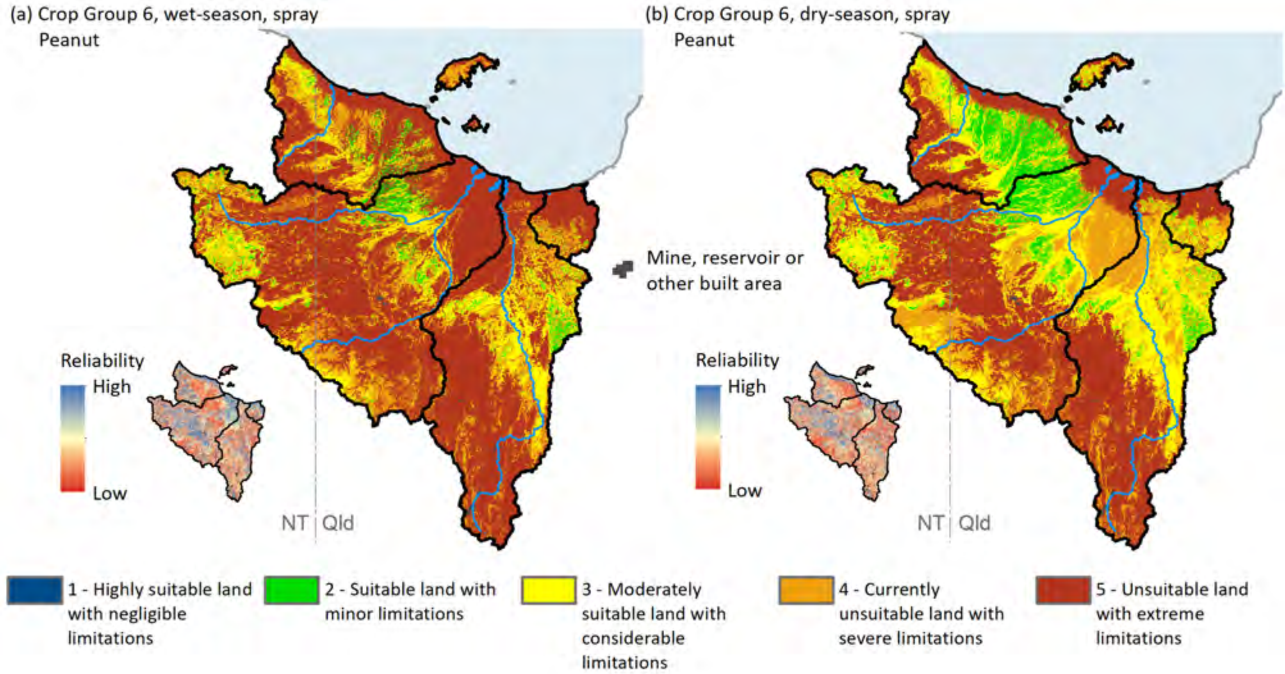

Figure 4-16 Modelled land suitability for peanut (Crop Group 6) using spray irrigation in the (a) wet season and (b) dry season

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-17 Peanut

Photo: Shutterstock

Table 4-19 Summary information relevant to the cultivation of root crops, using peanut as an example

PARAMETER	DESCRIPTION
Summary	Peanut (*Arachis hypogaea*) is a legume with a compact growth habit less than 0.6 m high. Most peanuts grown in Australia are grown in Queensland, primarily around Kingaroy, Bundaberg/Childers, Emerald and the Atherton Tablelands. Although peanut is technically an oilseed crop, its agronomic requirements are close to those of root crops. Peanut can be grown under irrigation, or rainfed where rainfall is suitable. Peanut varieties are either Virginia, runner or Spanish type. Virginia is used in the snack food industry, with runner and Spanish types used in the manufacturing industries. Harvesting of peanut is specialised, occurring in two distinct operations requiring specialised equipment. First, the crop roots are cut below the pods and the bush is pulled from the ground. In the second stage, the pods are removed from the rest of the bush in a process called threshing. Most peanut pods will then need drying prior to being safe for storage.
Growing season	Under irrigation, peanut can be grown in the wet season or dry season. Planting for wet-season production is from January to March, and planting for dry-season production is in August/September. Peanuts mature in 100 to 140 days.
Land suitability assessment	Land suitability for root crops is highly dependent on soils; lighter-textured soils are preferred. Approximately 34% of the catchments is suitable with moderate limitations or better under spray irrigation in the dry season and only 19% under spray irrigation in the wet season. Root crops are not suited to the heavier-textured soils in which furrow irrigation is used.
Irrigation system	Spray. Peanut is not suitable for the heavy clay soils required for surface irrigation.
Applied irrigation water (median)	5.2 ML/ha
Crop yield (median)	Rainfed: 2.3 to 3.2 t/ha; irrigated: 5.5 to 6.9 t/ha
Salinity tolerance	Moderately sensitive
Downstream processing	Peanuts must be dried prior to storage, which is commonly done in dryers, but under favourable conditions can be done in the field prior to threshing. Peanuts are then transferred to a processing facility (e.g. at Kingaroy) where they are shelled and graded, before being sent to market either raw or blanched, crushed for oil extraction or used in manufacturing peanut-based products for human consumption.
By-products	Peanut shell is used for mulch or animal feed. Crushed by-product is used in stockfeed mixes.
Production risks	Dry soil at harvest can damage the crop during pulling. Wet conditions after pulling can degrade crop quality. Hot, dry conditions reduce crop yield. High temperatures and high moisture content after harvest increase aflatoxin risk.
Rotations	Peanut is well suited to crop rotations with cereals such as maize or rice, and it can be planted in a sugarcane fallow. Peanut can be grown in the wet or dry season to suit other crops when grown in rotation in the Southern Gulf catchments. Peanut is a legume and therefore able to fix atmospheric nitrogen, providing a benefit to the following crop.
Management considerations	Ability to effectively use inoculants and desiccants. Harvesting and threshing equipment, access to dryers.
Complexity of management practices	Medium
Markets and emerging markets	Primarily domestic market
Prices	$1000/t
Opportunities and risks under a changing climate	Hotter and drier dry seasons could limit areas suitable for peanut.

4.4.6 Industrial (cotton)

Rainfed and irrigated cotton production are well established in Australia. The area of land devoted to cotton production varies widely from year to year, largely in response to availability of water. It varied from 70,000 to 600,000 ha between 2012–13 and 2021–22; a mean of 400,000 ha/year has been grown over the decade (ABARES, 2022). Likewise, the gross value of cotton lint production varied greatly between 2012–13 and 2021–22, from $0.3 billion in 2019–20 to $5.2 billion in 2021–22. Genetically modified cotton varieties were introduced in 1996 and now account for almost all cotton produced in Australia (over 99%). Australia was the fourth largest exporter of cotton in 2022, behind the United States, India and Brazil. Cottonseed is a by-product of cotton processing and is a valuable cattle feed. Mean lint production in Australia in 2015–16 was 8.8 bales/ha (ABARES, 2022).

Commercial cotton has a long but discontinuous history of production in northern Australia, including in Broome, the Fitzroy River and the Ord River Irrigation Area in WA; in Katherine and Douglas–Daly in the NT; and near Richmond and Bowen in northern Queensland. An extensive study undertaken by the Australian Cotton Cooperative Research Centre in 2001 (Yeates, 2001) noted that past ventures suffered from:

- a lack of capital investment
- too rapid a movement to commercial production
- a failure to adopt a systems approach to development
- climate variability.

Mistakes in pest control were also a major issue in early projects. Since the introduction of genetically modified cotton in 1996, yields and incomes from cotton crops have increased in most regions of Australia. The key benefits of genetically modified cotton over conventional cotton are savings in insecticide and herbicide use, and improved tillage management. In addition, farmers can now forward-sell their crop as part of a risk management strategy. Growers of genetically modified cotton are required to comply with the approved practices for growing the genetically modified varieties, including preventative resistance management.

Research and commercial test farming have demonstrated that the biophysical challenges are manageable if the growing of cotton is tailored to the climate and biotic conditions of northern Australia (Yeates et al., 2013). In recent years, irrigated cotton crops achieving more than 10 bales/ha have been grown successfully in the Burdekin irrigation region and experimentally in the Gilbert catchment of northern Queensland. Expansion of cotton through private investment is occurring in the catchments of the Leichhardt, Flinders and upper Mitchell rivers, Queensland. Cotton will be processed near Katherine, NT, at a gin commissioned in 2024. New genetically modified cotton using CSIRO varieties that are both pest- and herbicide-resistant are an important component of these northern cotton production systems.

Climate constraints will continue to limit production potential of northern cotton crops when compared to cotton grown in more favourable climate regions of NSW and Queensland. On the other hand, the low risk of rainfall occurring during late crop development favours production in northern Australia, as it minimises the likelihood of late-season rainfall, which can downgrade fibre quality and price. Demand for Australian cotton exhibiting long and fine attributes is expected to increase by 10% to 20% during the next decade and presents local producers with an opportunity to target production of high-quality fibre.

From a land suitability perspective, cotton is included in Crop Group 7 (Table 4-2; Figure 4-18). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated cotton (Crop Group 7; Table 4-2) using spray irrigation in the dry season. For spray irrigation in the wet season, nearly 3.1 million ha is suitable with moderate limitations (Class 3) or better. Land considered suitable with moderate limitations for furrow irrigation is limited to about 1.8 million ha in the dry season and about 780,000 ha in the wet season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy soils are too permeable. There is potential for rainfed cotton production in the wet season over an area of about 360,000 ha. From a land suitability perspective, Crop Group 7 contains both cotton and cereal crops; the latter are considered elsewhere in these crop synopses (Section 4.4.2).

In addition to a normal row planter and spray rig equipment used in cereal production, cotton requires access to suitable picking and module or baling equipment, as well as transport to processing facilities. Decisions on initial development costs and scale of establishing cotton production in the catchments would need to consider the need to source external contractors; this could provide an opportunity to develop local contract services to support a growing industry.

Cotton production is also highly dependent on access to processing plants (cotton gins). The closest processing facility for cotton grown in the Southern Gulf catchments is Emerald, Queensland. The first cotton gin in northern Australia will be processing in 2024 and is near Katherine in the NT.

Niche industrial crops, such as guar (*Cyamopsis tetragonoloba*) and chia (*Salvia hispanica*), may be feasible for the Southern Gulf catchments, but verified agronomic and market data on these crops are limited. Past research on guar has been conducted in the NT, and trials are currently underway. Hemp is a photoperiod-sensitive summer annual with a growing season between 70 and 120 days depending on variety and temperature. Hemp is well suited to growing in rotation with legumes, as hemp can use the nitrogen fixed by the legume crop. Industrial hemp can be harvested for grain with modifications to conventional headers, otherwise all other farming machinery for ground preparation, fertilising and spraying can be used. There are legislative restrictions to growing hemp in Australia, and jurisdictions including the NT are implementing industrial hemp legislation to license growing of industrial hemp to facilitate development of the industry. The companion technical report on agricultural viability and socio-economics (Webster et al., 2024) provides greater detail for a wider range of industrial crops.

Table 4-20 describes some key considerations relating to cotton production (Figure 4-19).

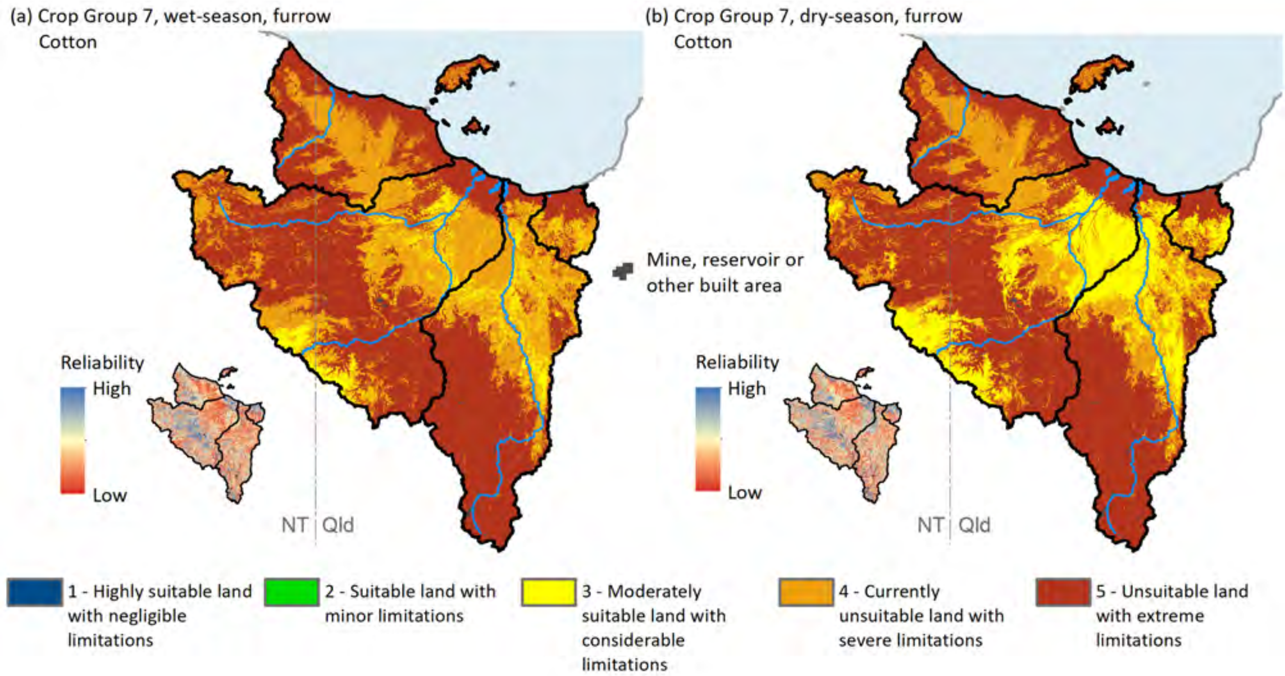

Figure 4-18 Modelled land suitability for cotton (Crop Group 7) using furrow irrigation in the (a) wet season and (b) dry season

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-19 Cotton

Photo: CSIRO

Table 4-20 Summary information relevant to the cultivation of cotton

PARAMETER	DESCRIPTION
Summary	Cotton (*Gossypium* spp.) is a shrub native to some tropical and subtropical regions, making up small on the world scale. However, due to a favourable climate during the growing season, Australia is recognised (along with Egypt) as currently producing the world's best cotton. A high proportion of Australian cotton is produced under irrigation, with rainfed crops sown into stored soil water resulting from fallowing processes. Cotton is marketed on qualities of grade, colour and fibre length. Cotton can be grown on the majority of deep clayey arable soils with adequate rainfall or supplementary irrigation. CSIRO genetically modified cotton has been successfully grown in the catchment of the Gilbert River and is currently grown in the catchments of the Leichhardt, Flinders, Burdekin and upper Mitchell rivers in Queensland, as well as the Douglas–Daly and Katherine regions in the NT.
Growing season	The planting window is from January to March for wet-season planting and April to June for dry-season planting.
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 44% of the catchments is suitable with moderate or minor limitations under spray irrigation in the dry season, this decreases to 17% for furrow irrigation in the dry season. Wet-season spray irrigation is limited to 29% of the catchment and wet-season furrow to 7%. About 3% is considered suitable with moderate limitations for rainfed production, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface, micro
Applied irrigation water (median)	About 5.1 ML/ha (furrow) for wet-season production and 6.0 ML/ha (furrow) for dry-season production
Crop yield (median)	Rainfed: 0.9 to 2.2 t/ha; irrigated: 7.6 to 10.7 bales/ha (wet-season crop), 1.7 to 6.8 bales/ha (dry-season crop)
Salinity tolerance	Tolerant: EC_e threshold for crop yield decline 7.7 dS/m
Downstream processing	Cotton gin
By-products	Cottonseed for stockfeed
Production risks	Prolonged waterlogging, reduced radiation due to cloud cover
Rotations	High potential for annual rotation
Management considerations	Picker, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	High
Markets and emerging markets	Price is influenced by international commodity markets. Australia is one of the world's largest exporters of raw cotton, with more than 90% of production exported, mainly to Asian spinning mill customers. China, Indonesia, Thailand, South Korea, Japan, Taiwan, Pakistan and Italy are the main buyers. Cotton growers have the option of delivering their cotton directly to a processor or having it marketed by an independent merchant. There are several pricing options available, including forward contracts.
Prices	Currently approximately $600 to $750 per bale
Opportunities and risks under a changing climate	Seasonal climate variability, water availability for irrigation

4.4.7 Forages

Forage, hay and silage are crops that are grown for consumption by animals. Forage is consumed in the paddock in which it is grown and is often referred to as 'stand and graze'. Hay is cut, dried, baled and stored before being fed to animals, usually in yards for weaning or when animals are being held for sale. Silage production resembles that for hay, but harvested forage is stored wet in wrapped bales or covered ground pits, where anaerobic fermentation occurs, to preserve the feed's nutritional value. Silage is often used as a production feed to grow animals to meet the specifications of premium markets.

Rainfed and irrigated production of forage crops is well established throughout Australia, with over 20,000 producers, most of whom are not specialist producers. Approximately 85% of forage production is consumed domestically, with the rest primarily used on live export ships, often in a pelleted form. The largest consumers are the horse, dairy and beef feedlot industries. Forage crops are also widely used in horticulture for mulches and for erosion control. There is a significant fodder trade in support of the northern beef industry, with further room for expansion since fodder costs constitute less than 5% of beef production costs (Gleeson et al., 2012).

The Southern Gulf catchments are suited to rainfed or irrigated production of forage, hay and silage. Rainfed and irrigated hay production currently occurs in the north-west Queensland region.

Non-leguminous forage, hay and silage

Forage crops, both annual and perennial, include sorghum, Rhodes grass, maize and Jarra grass (*Digitaria milanjiana* 'Jarra'), with specific forage cultivars. If irrigated, these grass forages require considerable amounts of water and nitrogen as they can be high yielding (20 to 40 t dry matter per ha per year). Given the rapid growth of grass forages, crude protein levels can decrease quickly to less than 7%, reducing their value as a feed. To maintain high nutritive value (10% to 15% crude protein), high levels of nitrogen fertiliser need to be applied, and in the case of hay the crop needs to be cut every 45 to 60 days.

After cutting, the crop grows back without the need for resowing. The rapid growth of forage during the wet season can make it challenging to match animal numbers to forage growth so that it is kept leafy and nutritious, and does not become rank and of low quality. Producing rainfed hay from perennials gives producers the option of irrigating when required or, if water becomes limiting, allowing the pasture to remain dormant before water again becomes available. Silage can be made from a number of crops, such as grasses, maize and forage sorghum.

From a land suitability perspective, Rhodes grass is included in Crop Group 14 (Table 4-2; Figure 4-20). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10%

of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.7 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated cropping of annual forages (Crop Group 12; Table 4-2) using spray irrigation in the dry season. For spray irrigation in the wet season, nearly 3.1 million ha is suitable with moderate limitations (Class 3) or better. Land considered suitable with moderate limitations for furrow irrigation is limited to about 1.8 million ha in the dry season and about 780,000 ha in the wet season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy soils are too permeable. There is potential for rainfed production of annual forages in the wet season over an area of about 620,000 ha. For perennial Rhodes grass, about 5.1 million ha is suitable with moderate or minor limitations under spray irrigation and about 1.8 million ha under furrow irrigation.

Apart from irrigation infrastructure, the equipment needed for forage production is machinery for planting and fertilising. Spraying equipment is also desirable but not necessary. Cutting crops for hay or silage requires more-specialised harvesting, cutting, baling and storage equipment.

Table 4-21 describes Rhodes grass production (Figure 4-21) for hay over 1 year of a 6-year cycle. Information similar to that in Table 4-21 for grazed forage crops is presented in the companion technical report on agricultural viability and socio-economics (Webster et al., 2024).

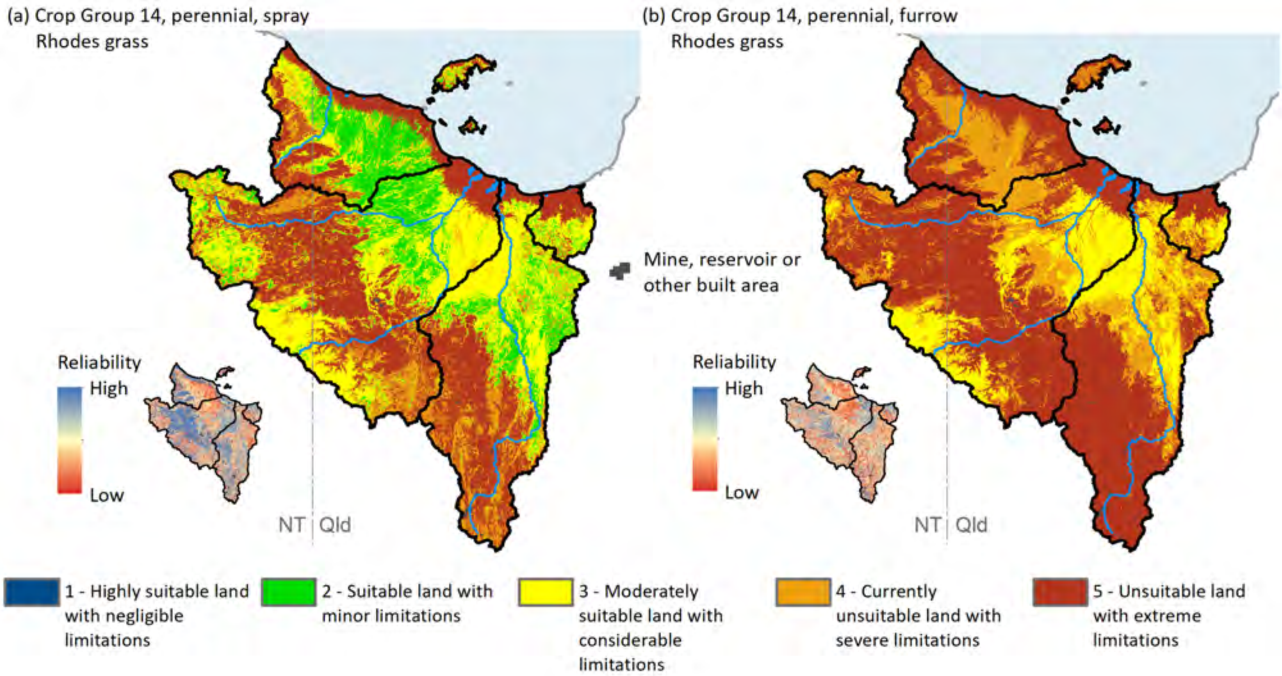

Figure 4-20 Modelled land suitability for Rhodes grass (Crop Group 14) using (a) spray irrigation and (b) furrow irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-21 Rhodes grass

Photo: CSIRO

Table 4-21 Rhodes grass production for hay over 1 year of a 6-year cycle

PARAMETER	DESCRIPTION
Summary	Rhodes grass (*Chloris gayana*) is a drought-tolerant perennial grass with a growth habit of 0.75 to 1.5 m in height. For rainfed production it prefers an annual rainfall of at least 650 mm, and it is well suited to a wide range of soils from light loams to heavy clays. Rhodes grass has a high leaf-to-stem ratio for a tropical grass, but it can quickly go to seed if not cut or grazed regularly. It is able to tolerate moderate levels of flooding and soil salinity. It is being increasingly used as an irrigated forage in northern Australia because of its high productivity, ease of establishment and demand.
Growing season	Under irrigation, planting occurs from the late dry season (September) through to the wet-season months. Growth continues, albeit more slowly, during the cooler dry-season months.
Land suitability assessment	For the perennial Rhodes grass, about 47% of the catchments is suitable with moderate limitations under spray irrigation but only about 17% under furrow irrigation. For annual forages, about 44% of the catchments is suitable with moderate limitations under spray irrigation in the dry season but only about 17% under furrow irrigation. For wet-season plantings, about 29% is suitable with moderate limitations under spray irrigation but about 7% under furrow irrigation. About 6% is considered suitable with moderate limitations for rainfed production in the wet season, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface
Applied irrigation water (median)	20.2 ML/ha for continuous perennial cropping with spray irrigation
Crop yield (median)	Irrigated: 39.2 to 46.3 t/ha for all-year production
Salinity tolerance	Moderately tolerant

PARAMETER	DESCRIPTION
Downstream processing	Available for direct delivery to end user
By-products	Potential use in biofuels
Production risks	Slow to establish without adequate water post-sowing. Low frost tolerance
Rotations	Perennial pasture. Potentially a component of a ley farming system, where crops are grown in rotation with grass pastures or legumes to disrupt carry-over pest and disease and improve soil fertility and structure.
Management considerations	Baler, forage cutter. Nitrogen fertiliser may be required to maintain productivity if not sown with legumes. No significant pests or diseases.
Complexity of management practices	Low
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages
Prices	Primarily for use on-farm. Price received will depend on drought conditions, with higher prices during dry periods.
Opportunities and risks under a changing climate	Drought tolerant, with some tolerance of moderate soil salinity (when established)

Forage legume

The use of forage legumes is similar to that of forage grasses. They are generally grazed by animals but can also be cut for silage or hay. Some forage legumes are well suited to the Southern Gulf catchments and would be considered among the more promising opportunities for irrigated agriculture (Figure 4-22).

Forage legumes are desirable because of their high protein content and their ability to fix atmospheric nitrogen in the soil. The nitrogen fixed during a forage legume phase is often in excess of requirements and remains in the soil as additional nitrogen available to subsequent crops. Forage legumes are being used by the northern cattle industry, and farmers primarily engaged in extensive cattle production could use irrigated forage legumes to increase the capacity of their enterprise, turning out more cattle from the same area. Cavalcade (*Centrosema pascuorum* 'Cavalcade') and lablab are currently grown in northern Australia and would be well suited to the Southern Gulf catchments. Hay crops are commonly used as a component of forage pellets that are used to feed live export cattle in holding yards and on boats during transport.

From a land suitability perspective, forage legumes such as Cavalcade and lablab are included in Crop Group 13 (Table 4-2; Figure 4-22). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the

Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Assuming unconstrained development, approximately 4.8 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) for irrigated forage legumes (Crop Group 13; Table 4-2) using spray irrigation in the dry season. For spray irrigation in the wet season, nearly 2.7 million ha is suitable with moderate limitations (Class 3) or better. Land considered suitable with moderate or minor limitations for furrow irrigation is limited to about 4.8 million ha in the dry season and about 580,000 ha in the wet season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy soils are too permeable. There is potential for rainfed forage legume production in the wet season over an area of about 220,000 ha.

The equipment needed for grazed forage legume production is similar to that for forage grasses: a planting method, with fertilising and spraying equipment, is desirable but not essential. Cutting crops for hay or silage requires more-specialised harvesting, cutting, baling and storage equipment.

Table 4-22 describes Cavalcade production over a 1-year cycle. The comments could be applied equally to lablab production (Figure 4-23).

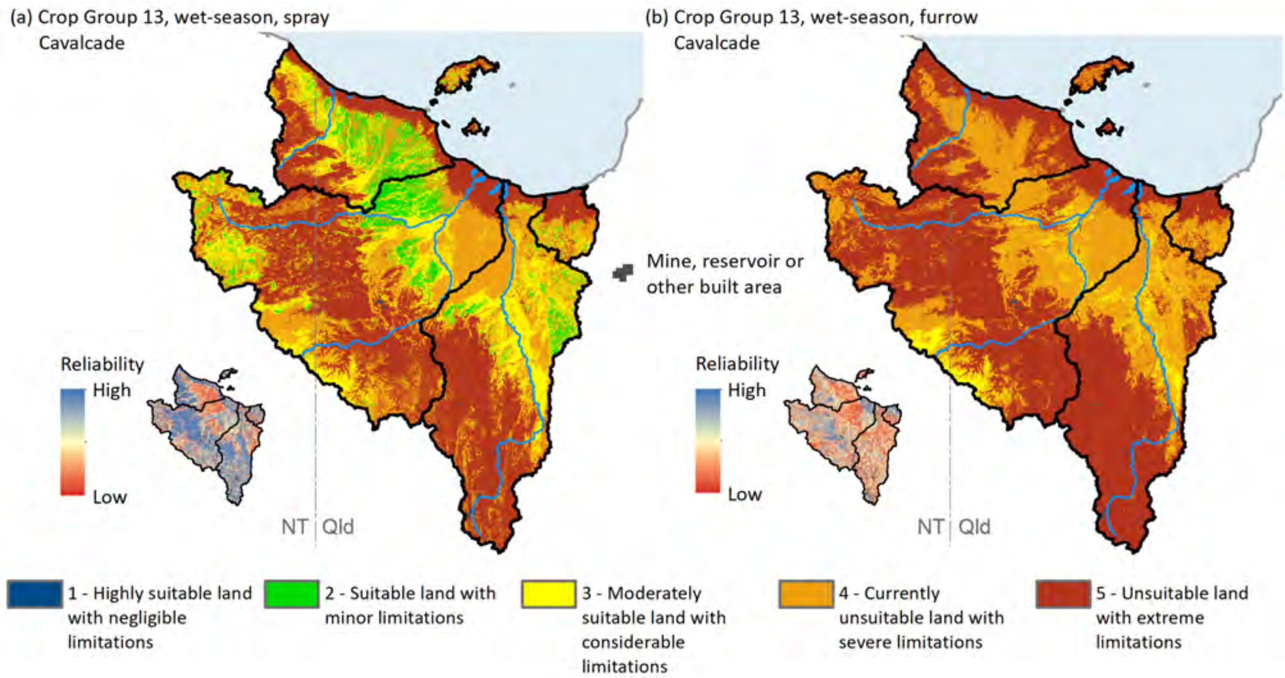

Figure 4-22 Modelled land suitability for Cavalcade (Crop Group 13) in the wet season using (a) spray irrigation and (b) furrow irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Table 4-22 Cavalcade production over a 1-year cycle

PARAMETER	DESCRIPTION
Summary	Cavalcade is an annual or short-lived perennial, twining legume, which is widely adapted to grazing, hay production and green manure. It is used in mixed cropping and livestock systems and sometimes as a legume ley (growing annual legume pastures between cereal crops) to address soil fertility. It is adapted to a wide range of soils and can survive prolonged waterlogging and partial submersion on the seasonally flooded coastal plains. It can also tolerate high internal moisture deficits during droughts.
Growing season	Under irrigation, Cavalcade is planted from October to December, before the wet season. It is grown for a few years as a short-lived perennial. If grown perennially, it requires periodic renovation.
Land suitability assessment	About 44% of the catchments is suitable for forage legumes under spray irrigation in the dry season but only 17% under furrow irrigation. In the wet season, about 25% is suitable with moderate or minor limitations under spray irrigation, with 5% suitable for furrow irrigation. About 2% is considered suitable with moderate limitations for rainfed production in the wet season, although opportunistic use in good wet seasons may allow a greater area in some years.
Irrigation system	Spray, surface
Applied irrigation water (median)	About 4 ML/ha (tape) to 6 ML/ha (furrow)
Crop yield (median)	Irrigated: about 6 to 8 t/ha
Salinity tolerance	Moderately sensitive
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stockfeed, potential use in biofuels
Production risks	Timing of crop establishment to avoid high-temperature stress at flowering and to maximise harvesting outside major rainfall periods. Does not tolerate heavy grazing.
Rotations	Annual rotation, break crop in cotton or sugar rotation
Management considerations	Baler, forage cutter
Complexity of management practices	Low
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages
Prices	Primarily used on-farm
Opportunities and risks under a changing climate	Drought tolerant (when established). Provides additional soil nitrogen in crop rotation

Figure 4-23 Lablab
Photo: CSIRO

4.4.8 Horticulture

Intensive horticulture is an important and widespread industry in Australia, occurring in every state, particularly close to capital city markets. Horticultural production varied between 2.9 and 3.3 Mt/year between 2012–13 and 2021–22, of which 65% to 70% was vegetables (ABARES, 2022). Unlike broadacre crops, most horticultural production in Australia is consumed domestically. The total gross value of horticultural production was $13.2 billion in 2021–22 (up from $9.3 billion in 2012–13), of which 24% was from exports (ABARES, 2022). Horticulture is also an important source of jobs, employing approximately a third of all people working in agriculture.

Horticultural production is more intensive than broadacre production and has a higher degree of risk, such as a short season of supply and highly volatile prices as a result of highly inelastic supply and demand. Managing these issues requires a heightened understanding of risks, markets, transport and supply chain issues (including associated interactions with other horticultural production regions).

Production is highly seasonal and can involve multiple crops produced on individual farms to manage labour resources. The importance of freshness in many horticultural products means seasonality of supply is important in the market. Farms in the Southern Gulf catchments have the advantage of being able to produce out-of-season supplies to southern markets. However, they must also compete with production regions in the NT and northern WA, which are already established production areas with associated infrastructure. Southern Gulf catchments may have an advantage over these regions in being geographically closer to most of the urban consumer centres of south-eastern Australia.

Horticulture (row crops)

Horticultural row crops are generally short-lived, annual crops, grown in the ground, such as seedless watermelons (*Citrullus lanatus*), rockmelon and honeydew melon (*Cucumis melo*), as well as sweet corn (*Zea mays)*. Almost all produce is shipped to capital cities where major central markets are located. Row crops such as watermelon and rockmelon use staggered plantings over a season (e.g. planted every 2 to 3 weeks) to extend the period over which harvested produce is sold. This strategy allows better use of labour and better management for risks of price fluctuations. Often only a short period of time with very high prices is enough to make melon production a profitable enterprise.

From a land suitability perspective, intensive horticulture row crops such as rockmelon are included in Crop Group 3 (Table 4-2). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

A wide range of horticultural row crops are considered in the land suitability analysis (crop groups 3, 4, 5, 6 and 18; Table 4-2; Figure 4-24). Assuming unconstrained development, between about 3.4 million ha and 4.9 million ha of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) using spray or trickle irrigation in the dry season. Land considered suitable with moderate limitations for furrow irrigation of sweet corn (Crop Group 18) is limited to about 1.7 million ha in the dry season and only 780,000 ha in the wet season, due to inadequate soil drainage in clay soils (and/or because gilgais are too deep) and because the loamy soils are too permeable.

Horticultural row crops are well established throughout the NT, Burdekin and Mareeba–Dimbulah Water Supply Scheme region in Queensland. The NT melon industry, consisting of watermelon (seedless), rockmelon and honeydew, produces approximately 25% of Australia’s melons. Melon production would be well suited to the Southern Gulf catchments, which could compete with NT production.

Horticulture typically requires specialised equipment and a large labour force. Therefore, a system for attracting, managing and retaining sufficient staff is also required. Harvesting is often by hand, but packing equipment is highly specialised. Irrigation is generally with micro or trickle equipment, but overhead spray is also feasible. Leaf fungal diseases need to be carefully managed when using spray irrigation. Micro spray equipment has the advantage of being able to deliver fertiliser along with irrigation. Table 4-23 describes some key considerations relating to row crop horticulture production, with rockmelon (Figure 4-25) as an example.

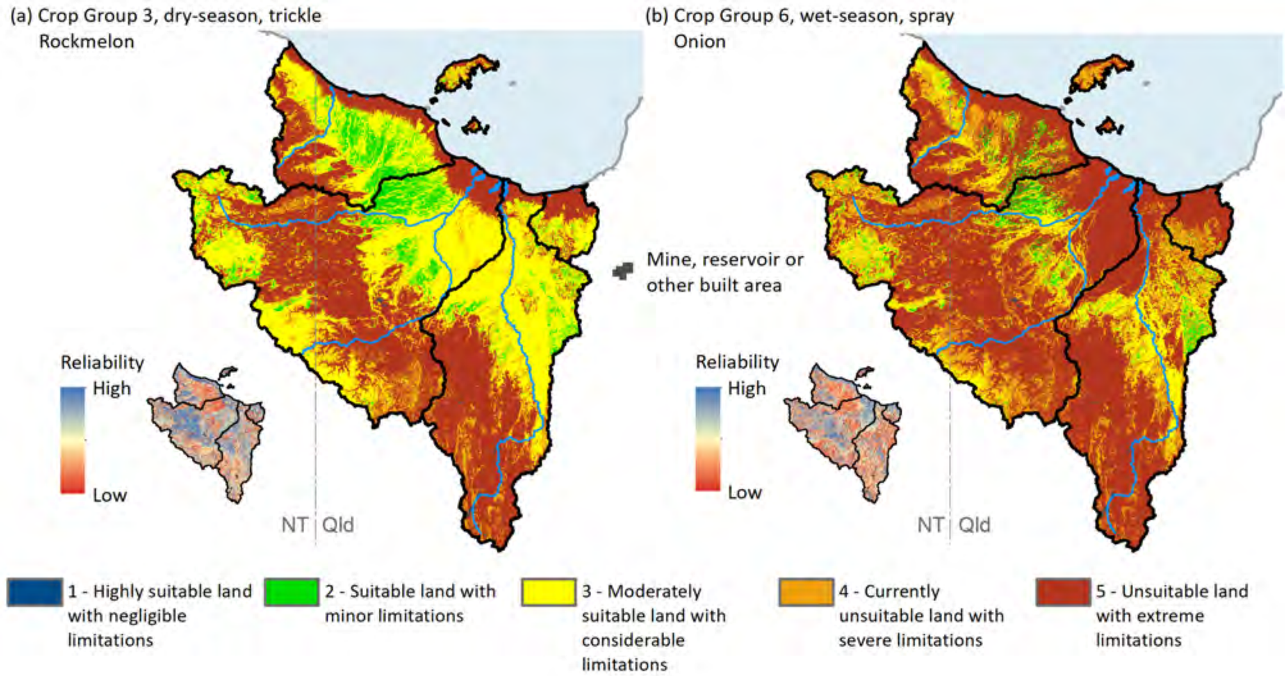

Figure 4-24 Modelled land suitability for (a) cucurbits (e.g. rockmelon, Crop Group 3) using trickle irrigation in the dry season and (b) root crops such as onion (Crop Group 6) using spray irrigation in the wet season

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-25 Rockmelon

Photo: Shutterstock

Table 4-23 Summary information relevant to row crop horticulture production, with rockmelon as an example

PARAMETER	DESCRIPTION
Summary	Rockmelon is an annual crop grown in plastic mulch with high fertiliser inputs. It is a high-value crop, so management practices are optimised to produce the highest possible crop yield at the highest quality. In the Southern Gulf catchments, rockmelon can be produced at times when more-southern growing regions cannot produce, therefore attracting a premium price.
Growing season	Production is timed to be mostly June to early November, during the dry season.
Land suitability assessment	A selection of different types of horticultural row crops were considered in the land suitability analysis. Typically, about 32% to 46% of the catchments is suitable with moderate or minor limitations in the dry season under spray or trickle irrigation. Disease risk during the wet season limits horticultural row crop production. Under dry-season furrow irrigation for sweet corn production, about 16% is suitable with moderate limitations.
Irrigation system	Micro, trickle or spray
Salinity tolerance	Low. Irrigation water needs to be checked prior to crop establishment.
Downstream processing	Requires access to packing equipment, labour, boxes and refrigerated transport to market.
By-products	Packing shed waste potentially used as animal feed
Production risks	Pest and disease control essential
Rotations	Rockmelon is commonly grown after a green manure crop such as forage sorghum.
Management considerations	Cultivation equipment, spray rig, fertiliser, planting equipment, plastic mulch, micro irrigation and fertigation equipment, insect pest control (chemical resistance). There is a high labour requirement, and specialised equipment is needed for harvesting, grading and packing.
Complexity of management practices	High
Markets and emerging markets	Most production goes to Australian city markets (Brisbane, Sydney, Melbourne, Adelaide, Perth). Refrigerated transport costs can be high.
Prices	Prices vary greatly depending on current supply and demand.
Opportunities and risks under a changing climate	A drier climate may allow a longer growing period, but there will be trade-offs with higher temperatures.

Horticulture (tree crops)

Some fruit and tree crops, such as mangoes and citrus (*Citrus* spp.), are well suited to the climate of the Southern Gulf catchments. Other species, such as avocado (*Persea americana*) and lychee (*Litchi chinensis*), are not likely to be as well adapted to the climate due to high temperatures and low humidity. Tree crops are generally not well suited to cracking clays, which make up some of the arable soils for irrigated agriculture in the Southern Gulf catchments. Horticultural tree production is more feasible on the lighter, well-drained soils in the north-west of the Southern Gulf catchments.

Fruit production shares many of the marketing and risk features of horticultural row crops, such as a short season of supply and highly volatile prices as a result of highly inelastic supply and demand. Managing these issues requires a heightened understanding of risks, markets, transport and supply chain issues. The added disadvantage of fruit tree production is the time lag between planting and production, meaning decisions to plant need to be made with a long time frame for production and return in mind. Mango production in the NT is buffered somewhat against large-scale competition as its crop matures earlier than the main production areas in Queensland, and it can achieve high returns. Mango production in the NT had a gross value of $129 million in 2020, accounting for 38% of the $341 million total value of horticultural production in the NT and half of all mangoes produced in Australia (Sangha et al., 2022).

The perennial nature of tree crops makes a reliable year-round supply of water essential. Some species, such as mango and cashew (*Anacardium occidentale*), can survive well under mild water stress until flowering. It is critical for optimum fruit and nut production that trees are not water stressed from flowering through to harvest, approximately from June to between November and February, depending on plant species and variety. This is a period in the Southern Gulf catchments when very little rain falls, and farmers would need to have a system in place to access reliable irrigation water during this time. High night-time minimum temperatures can reduce flowering in mangoes, although potential production regions in Southern Gulf catchments should not experience these temperatures extremes.

From a land suitability perspective, intensive horticultural tree crops such as mango are included in Crop Group 1, the monsoonal tropical tree crops (Table 4-2). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

A wide range of horticultural tree crops are considered in the land suitability analysis (crop groups 1, 2, 20 and 21; Table 4-2; Figure 4-26). Assuming unconstrained development, between about 860,000 ha (papaya/cashew/macadamia) and 3.9 million ha (e.g. mango) of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) using spray or trickle irrigation. Furrow irrigation was not considered for horticultural tree crops.

Specialised equipment is required for fruit and nut tree production. The requirement for a timely and significant labour force necessitates a system for attracting, managing and retaining sufficient staff. In a remote location the cost of providing accommodation to such staff may be significant. Tree-pruning and packing equipment is highly specialised for the fruit industry, as are the micro irrigation systems typically used in horticulture.

Table 4-24 describes some key considerations relating to mango production (Figure 4-27) in the Southern Gulf catchments, as an exemplar of the considerations relating to tree crop production more broadly. Similar information for other fruit tree crops is described in the companion technical report on agricultural viability and socio-economics (Webster et al., 2024).

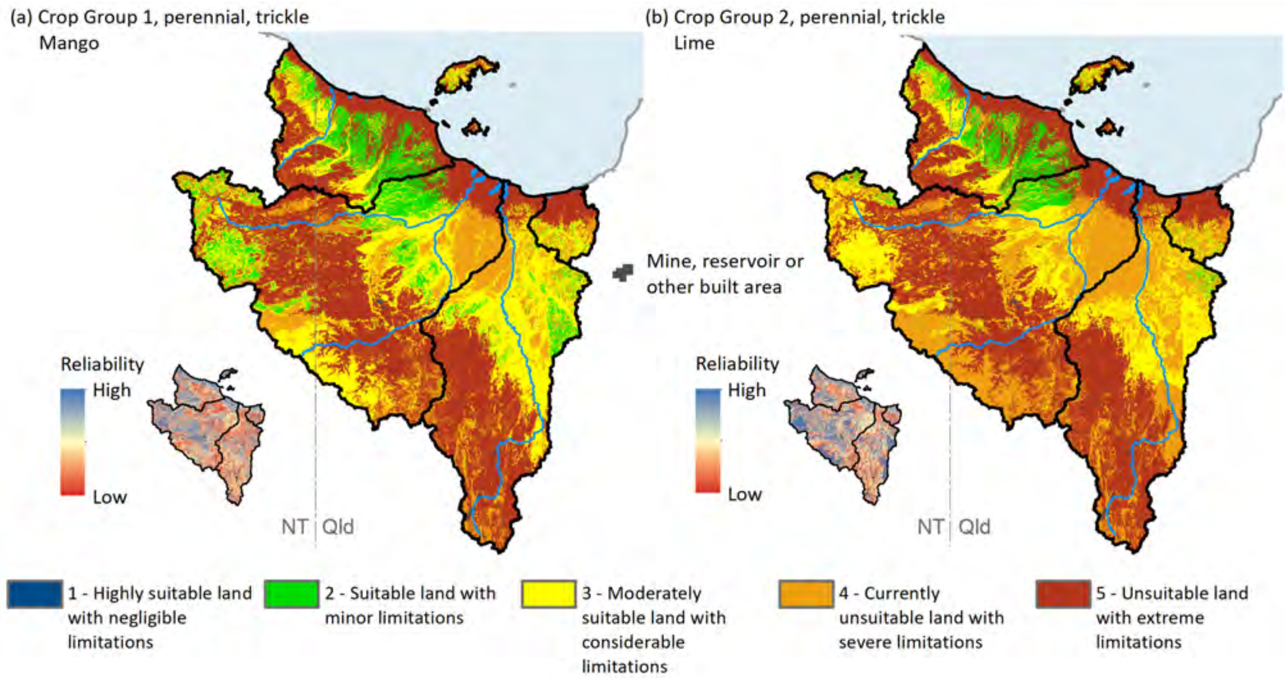

Figure 4-26 Modelled land suitability for (a) mango (Crop Group 1) and (b) lime (Crop Group 2), both grown using trickle irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-27 Mango

Photo: Shutterstock

Table 4-24 Summary information relevant to tree crop horticulture production, with mango as an example

PARAMETER	DESCRIPTION
Summary	Mango is one of the major horticultural tree crops grown in Australia. Mangoes are the largest horticultural commodity in the NT, where approximately 6000 ha currently produce about half of Australia's mangoes. Queensland is responsible for about 43% of Australia's total mango production. The main production areas are around Darwin and Katherine in the NT and the Mareeba, Bowen and Burdekin areas in Queensland
Growing season	Mango harvest starts in September/October in the Southern Gulf catchments and extends to the end of December depending on variety.
Land suitability assessment	Between about 8% (papaya/cashew/macadamia under spray irrigation) and 36% (mango under both spray and trickle irrigation) of the catchments is suitable with moderate limitations for horticultural tree crops.
Irrigation system	Micro, need capacity to apply up to 0.3 ML per ha per week in peak demand
Applied irrigation water (median)	7.4 ML/ha
Crop yield (median)	Irrigated: 9.3 t/ha Kensington Pride; 17.5 t/ha PVR (e.g. Calypso)
Salinity tolerance	Sensitive
Downstream processing	Requires local processing soon after harvest. Unripe fruits are used in pickles, chutneys and salads. Ripe fruits can be eaten fresh or frozen, or they can be dehydrated, canned or made into products such as jams and juices.
By-products	None
Production risks	Susceptible to cold. Many varieties have irregular yields, with a heavy crop one year followed by several lighter crops.
Rotations	Perennial tree crop not suited for rotation. Could be planted for alley cropping
Management considerations	Packing equipment, harvest aids. A wide range of climate zones in northern Australia provides opportunities to maintain a sustained period for supplying the domestic market. The most common variety grown in the NT is Kensington Pride, while other varieties are grown on a limited scale to extend seasonal availability or supply niche markets.
Complexity of management practices	Medium
Markets and emerging markets	Most fruit are sold on the domestic market with only a small amount exported.
Prices	Highly variable depending on timing
Opportunities and risks under a changing climate	Increasing opportunity to supply processed market for canned mango, juice and mango-flavoured products.

PVR = plant variety rights.

4.4.9 Plantation tree crops (silviculture)

Of the plantation tree crops that could be grown in the Southern Gulf catchments, Indian sandalwood (*Santalum album*) and African mahogany (*Khaya spp*.) are likely to be the most economically feasible. Many other plantation species could be grown but returns are much lower than for sandalwood or African mahogany. African mahogany is well established in plantations near Katherine and in north Queensland. Indian sandalwood is grown in the Ord River Irrigation Area (WA), around Katherine (NT) and in northern Queensland.

Plantation tree crops require over 15 years to mature, but once established they can tolerate prolonged dry periods. Irrigation water is critical in the establishment and in the first 2 years of a plantation for a number of species. In the case of Indian sandalwood (which is a hemi root parasite), the provision of water is for not only the trees themselves but also the leguminous host plant.

From a land suitability perspective, plantation tree crops such as Indian sandalwood, African mahogany and teak (*Tectona grandis*) are included in crop groups 15, 16 and 17 (Table 4-2). Cracking clay soils (Vertosols) make up 23% of the catchment; they are principally found on floodplains and alluvial plains of the Armraynald Plain and Barkly Tableland physiographic units. Flooding, access and trafficability in the wet season are common constraints across the lower parts of the Armraynald Plain and crop tolerance to poor soil drainage conditions restricts wet-season cropping in these areas. Effective rooting depth is deep to very deep (1.2 to 1.5 m) and the clay texture means the soils have a very high (>220 mm) soil AWC. Much of this area is suitable (with moderate or minor limitations) for spray irrigation in the dry season, but inadequate drainage in the wet season substantially reduces the area suitable for wet-season spray irrigation. Sandy soils have formed on the Doomadgee Plain (marked S1 and S4 on Figure 2-5) and the Gulf Fall (marked S3 on Figure 2-5). In total, the red, brown, yellow and grey sandy soils make up 10% of the area. Friable non-cracking clay or clay loam soils found along the middle reaches of the Leichhardt River make up only about 3% of the area but have potential for agriculture, as do the loamy soils (less than 3% of the area) on the Nicholson River, the Doomadgee and Cloncurry plains and other isolated areas. Shallow and/or rocky soils make up 56% of the catchments and are unsuitable by definition.

Depending on the specific tree species being planted and their tolerance to poorly drained soils and waterlogging, the suitable areas vary considerably. A range of silviculture trees were considered in the land suitability analysis (crop groups 15, 16 and 17; Table 4-2). Assuming unconstrained development, between about 3.1 million ha (teak) and 5.1 million ha (African mahogany) of the Southern Gulf catchments is considered to be suitable with moderate limitations (Class 3; Table 4-1) or better (Class 2 or Class 1) using trickle irrigation (Figure 4-28). Furrow irrigation was considered for Indian sandalwood only and about 810,000 ha was assessed as suitable with moderate limitations. Table 4-25 describes Indian sandalwood production (Figure 4-29).

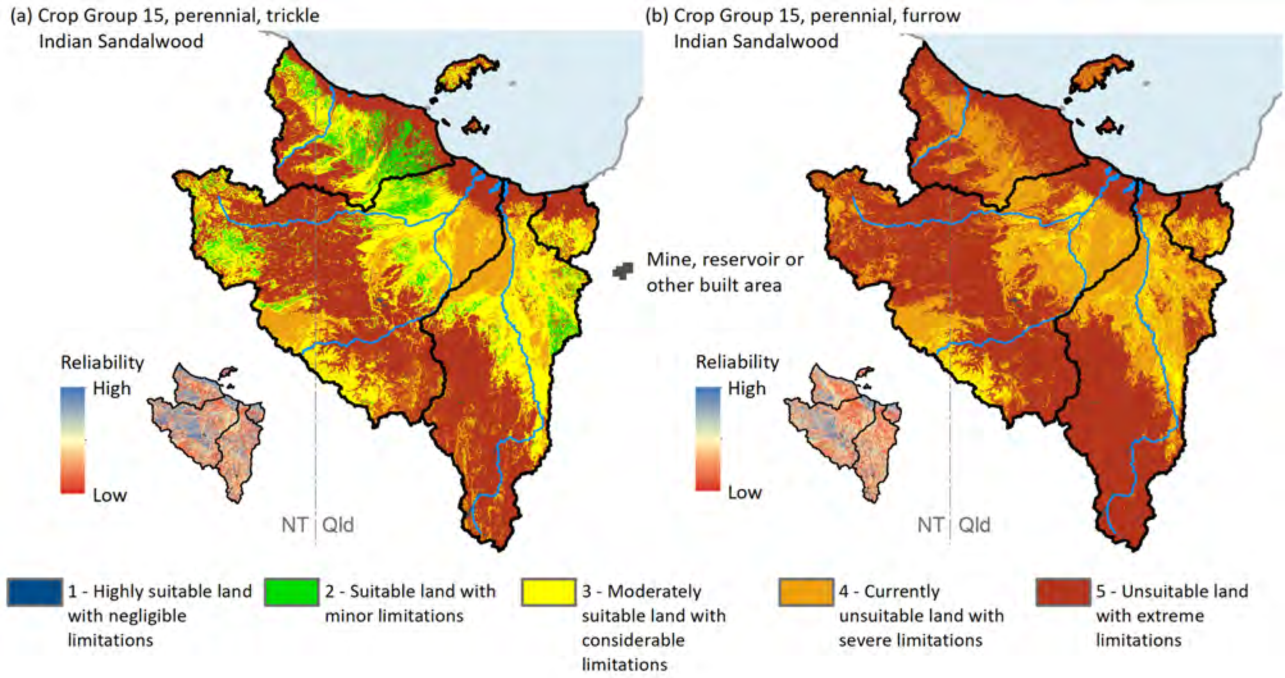

Figure 4-28 Modelled land suitability for Indian sandalwood (Crop Group 15) grown using (a) trickle or (b) furrow irrigation

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset maps are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Figure 4-29 Indian sandalwood and host plants

Indian sandalwood trees are those with a darker trunk and leaves, in a line left of centre in the image.

Photo: CSIRO

Table 4-25 Summary information for Indian sandalwood production

PARAMETER	DESCRIPTION
Summary	Sandalwood is a medium-sized, hemiparasitic (partially parasitic but also producing food via photosynthesis) tree grown for its aromatic wood and essential oils. The key product of value from sandalwood trees is the heartwood, which contains most of the oil and scented wood. Heartwood starts to develop when the tree is about 10 years old, with the proportion of heartwood (and value of the plantation) increasing with age after that time. Commercially viable sandalwood can take at least 15 years to reach harvestable maturity, but many plantations are not harvested for 20 to 35 years. Large areas of Indian sandalwood have been planted in the Ord River Irrigation Area, with some plantations reaching maturity in 2013. Plantations are also growing in the Katherine, Mataranka and Douglas–Daly regions. Production risks are mostly associated with the long period of time from planting to harvest and uncertainty about the market for sandalwood in 20 years.
Land suitability assessment	About 35% of the Southern Gulf catchments is suitable with moderate limitations for Indian sandalwood under trickle irrigation, but only 7% under furrow irrigation. For African mahogany, about 47% of the catchment is suitable under trickle irrigation with moderate or minor limitations. Only 28% is suitable for teak.
Irrigation system	Surface, micro
Irrigation demand	About 6 ML/ha
Crop yield (median)	Heartwood 8 to 10 t/ha at 15 years; oil yield from heartwood 2% to 7%
Salinity tolerance	Unknown
Downstream processing	Sandalwood can be processed in Australia or exported overseas for oil extraction.
By-products	Spent pulp after oil extraction is available for production of incense. Sandalwood nuts are edible, and there may also be potential markets in the cosmetics industry. The host plants may be harvested for timber or biofuels.
Production risks	Long length of time between planting and harvest. Termites can significantly reduce the yields of plantations. Synthetic and biosynthetic sandalwood oil is the greatest threat to the Australian sandalwood industry.
Rotations	Perennial tree crop not suited for rotation with other species. Sandalwood requires a host plant to supply water and nutrients.
Management considerations	Indian sandalwood trees may require several hosts over their life span. The first host is usually a herbaceous plant (e.g. *Alternanthera* spp.) introduced to the container-grown sandalwood 1 month prior to planting. The second short-term host (e.g. *Sesbania formosa*) is used to produce rapid sandalwood growth and will die 2 to 4 years after establishment (the sandalwood and short- and long-term hosts are usually planted at the same time). A long-term host (e.g. *Cathormion umbellatum*) supports the sandalwood over its production life (Barbour, 2008). Host species also need to be suited to local soil type and climate. Two to three host trees are required per sandalwood tree. Using several species of host plants will minimise risks from pests and diseases. Harvesting is usually done by contractors. Weed control is important and must use methods that do not negatively affect the sandalwood or host plant.
Complexity of management practices	Medium
Markets and emerging markets	Globally, sandalwood is highly valued due to the presence of unique aromatic substances in the heartwood, and it is important to certain cultures and religions. The incense industry is the largest consumer of sandalwood material. High prices are paid for good-quality timber suitable for carving, but the proportion of such material is low. The next most valuable product is the oil, which is the main driver of international trade and is sought after for high-value end uses such as perfumery. The traditional markets of Taiwan, Hong Kong and China are the biggest consumers of sandalwood.

PARAMETER	DESCRIPTION
Prices	Prices have increased over the past decade in response to a steady decline in worldwide supply.
Opportunities and risks under a changing climate	Can take advantage of soil water at any time of year Planting several species of sandalwood and host plants together makes the plantation more resilient to climate change. Sandalwood trees are not fire tolerant.

4.4.10 Niche crops

Niche crops such as guar, chia, quinoa (*Chenopodium quinoa*), bush products and others may be feasible in the Southern Gulf catchments, but limited verified agronomic or market data are available for these crops. Niche crops are niche due to the limited demand for their products. As a result, small-scale production can lead to very attractive prices, but only a small increase in productive area can flood the market, leading to greatly reduced prices and making production unsustainable.

There is growing interest in bush products but insufficient publicly available information for inclusion with the analyses of irrigated crop options in this report. Bush product production systems could take many forms, from culturally appropriate wild harvesting targeting Indigenous cultural and environmental co-benefits to intensive mechanised farming and processing, resembling something like macadamia (*Macadamia integrifolia*) farming, with multiple possible combinations and variants in between. The choice of production system would have implications for the extent of Indigenous participation in each stage of the supply chain (farming, processing, marketing and/or consumption), the co-benefits that could be achieved, the scale of the markets that could be accessed (in turn affecting the scale of the industry for that bush product), the price premiums that produce may be able to attract and the viability of those industries. The current publicly available information on bush products mainly focuses on eliciting Indigenous aspirations, biochemical analysis (for safety, nutrition and efficacy of potential health benefits of botanicals), and considerations of safeguarding Indigenous intellectual property (e.g. Woodward et al., 2019). Analysing bush products in a comparable way to other crop options in this report would first require these issues to be resolved, for communities to agree on the preferred type of production systems (and pathways for development), and for agronomic information on yields, production practices and costs to be publicly available.

Past research on guar has been conducted in the NT, and trials are underway in northern Queensland, which could prove future feasibility. There is increasing interest in non-leguminous, small-seeded crops such as chia and quinoa, which have high nutritive value. The market size for these niche crops is quite small compared with cereals and pulses, so the scale of production is likely to be small in the short to medium term.

There is a small, established chia industry in the Ord River Irrigation Area of WA, but its production and marketing statistics are largely commercial-in-confidence. Nearly all Australian production of chia is contracted to The Chia Company of Australia or is exported to China. In Australia, The Chia Company produces whole chia seeds, chia bran, ground chia seed and chia oil for wholesale and retail sale, and it exports these products to 36 countries.

The growing popularity of quinoa in recent years is attached to its marketing as a superfood. It is genetically diverse and has not been the subject of long-term breeding programs. This diversity means it is well suited to a range of environments, including northern Australia, where its greatest opportunity is as a short-season crop in the dry season under irrigation. It is a high-value crop with farm gate prices of about $1000/t. Trials of quinoa production have been conducted at the Katherine Research Station in the NT (approximately 600 km north-west of the Southern Gulf catchments), with reasonable yields being returned. More trials are required in the various northern environments before quinoa could be recommended for commercial production.

4.5 Aquaculture

4.5.1 Introduction

There are considerable opportunities for aquaculture development in northern Australia given its natural advantages of a climate suited to farming valuable tropical species, large areas identified as suitable for aquaculture, political stability and proximity to large global markets. The main challenges to developing and operating modern and sustainable aquaculture enterprises are regulatory issues, global cost competitiveness and the remoteness of much of the suitable land area. A comprehensive situational analysis of the aquaculture industry in northern Australia (Cobcroft et al., 2020) identifies key challenges, opportunities and emerging sectors. This section draws on a recent assessment of the opportunities for aquaculture in northern Australia in the Northern Australia Water Resource Assessment technical report on aquaculture (Irvin et al., 2018), summarising the three most likely candidate species (Section 4.5.2), overviewing production systems (Section 4.5.3), land suitability for aquaculture within the Southern Gulf catchments (Section 4.5.4) and the financial viability of different options for aquaculture development (Section 4.5.5).

4.5.2 Candidate species

The three species with the most aquaculture potential in the catchments of the Southern Gulf rivers are black tiger prawns (*Penaeus monodon*), barramundi (*Lates calcarifer*), and red claw (*Cherax quadricarinatus*). The first two species are suited to many marine and brackish water environments of northern Australia and have established land-based culture practices and well-established markets for harvested products. Prawns could potentially be cultured in either extensive (low density, low input) or intensive (higher density, higher input) pond-based systems in northern Australia, whereas land-based culture of barramundi would likely be intensive. Red claw is a freshwater crayfish that is currently cultured by a much smaller industry than the other two species.

Black tiger prawns

Black tiger prawns (Figure 4-30) are found naturally at low abundances across the waters of the western Indo-Pacific region, with wild Australian populations making up the southernmost extent of the species. Within Australia, the species is most common in the tropical north, but does occur at lower latitudes.

Figure 4-30 Black tiger prawns
Photo: CSIRO

Barramundi

Barramundi (Figure 4-31) is the most highly produced and valuable tropical fish species in Australian aquaculture. Barramundi inhabit the tropical north of Australia from the Exmouth Gulf in WA through to the Noosa River on Queensland's east coast. It is also commonly known as the 'Asian sea bass' or 'giant sea perch' throughout its natural areas of distribution in the Persian Gulf, the western Indo-Pacific region and southern China (Schipp et al., 2007). The attributes that make barramundi an excellent aquaculture candidate are fast growth (reaching 1 kg or more in 12 months), year-round fingerling availability, well-established production methods and hardiness (i.e. they have a tolerance to low oxygen levels, high stocking densities and handling, as well as a wide range of temperatures) (Schipp et al., 2007). In addition, barramundi are euryhaline (able to thrive and be cultured in fresh and marine water), but freshwater barramundi can have an earthy flavour.

Figure 4-31 Barramundi
Photo: CSIRO

Red claw

Red claw is a warm-water crayfish species that inhabits still or slow-moving water bodies. The natural distribution of red claw is from the tropical catchments of Queensland and the NT to southern New Guinea. The name 'red claw' is derived from the distinctive red markings present on the claws of the male crayfish. The traits of red claw that make them attractive for aquaculture production are a simple life cycle, which is beneficial because complex hatchery technology is not required (Jones et al., 1998); their tolerance of low oxygen levels (<2 mg/L), which is beneficial in terms of handling, grading and transport (Masser and Rouse, 1997); their broad thermal tolerance, with optimal growth achievable between 23 and 31 °C; and their ability to remain alive out of water for extended periods.

4.5.3 Production systems

Overview

Aquaculture production systems can be broadly classified into extensive, semi-intensive and intensive systems. Intensive systems require high inputs and expect high outputs: they require high capital outlay and have high running costs; they require specially formulated feed and specialised breeding, water quality and biosecurity processes; and they have high production per hectare (in the order of 5000 to 20,000 kg per ha per crop). Semi-intensive systems involve stocking seed from a hatchery, routine provision of a feed, and monitoring and management of water quality. Production is typically 1000 to 5000 kg per ha per crop. Extensive systems are characterised by low inputs and low outputs: they require less-sophisticated management and often require no supplementary feed because the farmed species live on naturally produced feed in open-air ponds. Extensive systems produce about half the volume of global aquaculture production, but there are few commercial operations in Australia.

Water salinity and temperature are the key parameters that determine species selection and production potential for any given location. Suboptimal water temperature (even within tolerable limits) will prolong the production season (because of slow growth) and increase the risk of disease, reducing profitability.

The primary culture units for land-based farming are purpose-built ponds. Pond structures typically include an intake channel, production pond, discharge channel and a bioremediation pond (Figure 4-32). The function of the pond is as a containment structure – an impermeable layer between the pond water and the local surface water and groundwater. Optimal sites for farms are flat and have sufficient elevation to enable ponds to be completely drained between seasons. It is critical that all ponds and channels can be fully drained during the off (dry-out) season to enable machinery access to sterilise and undertake pond maintenance.

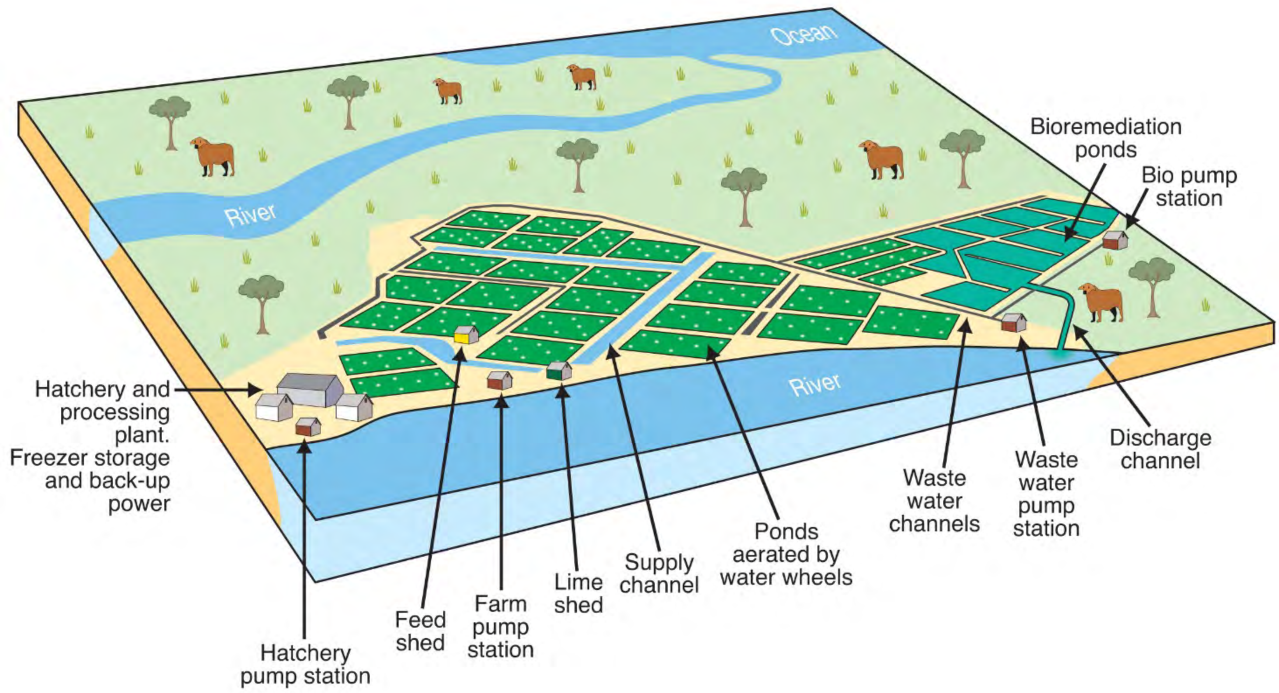

Figure 4-32 Schematic of marine aquaculture farm

Most production ponds in Australia are earthen. Soils for earthen ponds should have low permeability and high structural stability. Ponds should be lined if the soils are permeable. Synthetic liners have a higher capital cost but are often used in more-intensive operations, which require high levels of aeration – conditions that would lead to significant erosion in earthen ponds.

Farms use aerators (typically electric paddlewheels and aspirators) to help maintain optimal water quality in the pond, provide oxygen and create a current that consolidates waste into a central sludge pile (while keeping the rest of the pond floor clear). A medium-sized (50 ha) prawn farm in Australia uses around 4 GWh annually, accounting for most of an enterprise's energy use (Paterson and Miller, 2013). Backup power capacity sufficient to run all the aerators on the farm, usually with a diesel generator, is essential to be able to cope with power failures. Extensive production systems do not require aeration in most cases.

Black tiger prawns

A typical pond in the Australian black tiger prawn industry is rectangular, about 1 ha in area and about 1.5 m in depth. The ponds are either wholly earthen, lined on the banks with black plastic and earthen bottoms or (rarely in Australia) fully lined. Pond grow-out of black tiger prawns typically operates at stocking densities of 25 to 50 individuals per square metre (termed 'intensive' in this report). These pond systems are fitted with multiple aeration units, which could double from 8 to 16 units as the biomass of the prawn crop increases (Mann, 2012).

At the start of each prawn crop, pond bottoms are dried, and unwanted sludge from the previous crop is removed. If needed, additional substrate is added. Before filling the ponds, lime is often added to buffer pH, particularly in areas with acid-sulfate soils. The ponds are then filled with filtered seawater and left for about 1 week prior to postlarval stocking. Algal blooms in the water are encouraged through addition of organic fertiliser to provide shading for prawns, discourage benthic algal growth and stimulate growth of plankton as a source of nutrition (QDPIF, 2006). Postlarvae are purchased from hatcheries and grow rapidly into small prawns in the first month after stocking, relying mainly on the natural productivity (zooplankton, copepods and algae) supported by the algal bloom for their nutrition. Approximately 1 month after the prawns are stocked, pellet feed becomes the primary nutrition source. Feed is a major cost of prawn production: around 1.5 kg of feed is required to produce 1 kg of prawns. Prawns typically reach optimal marketable size (30 g) within 6 months. After harvest, prawns are usually processed immediately, with larger farms having their own production facilities that enable grading, cooking, packaging and freezing.

Effective prawn farm management involves maintaining optimal water quality conditions, which becomes progressively complex as prawn biomass and the quantity of feed added to the system increase. As prawn biomass increases, so too does the biological oxygen demand of the microbial population within the pond that is breaking down organic materials. This requires increases in mechanical aeration and water exchanges (either fresh or recycled from a bioremediation pond). In most cases water salinity is not managed, except through seawater exchange, and will increase naturally with evaporation and decrease with rainfall and flooding. Strict regulation of the quality and volume of water that can be discharged means efficient use of water is standard industry practice. Most Australian prawn farms allocate up to 30% of their productive land for water treatment by pre-release containment in settlement systems.

Barramundi

The main factors that determine productivity of barramundi farms are water temperature, dissolved oxygen levels, effectiveness of waste removal, expertise of farm staff and the overall health of the stock. Barramundi are susceptible to a variety of bacterial, fungal and parasitic organisms. They are at highest risk of disease when exposed to suboptimal water quality conditions (e.g. low oxygen or extreme temperatures).

Due to the cost and infrastructure required, many producers elect to purchase barramundi fingerlings from independent hatcheries, moving fish straight into their nursery cycle. Regular size grading is essential during the nursery stage to minimise aggressive and cannibalistic behaviour: size grading helps to prevent mortalities and damage from predation on smaller fish, and it assists with consistent growth.

Ponds are typically stocked to a biomass of about 3 kg per 1000 L. Under optimal conditions barramundi can grow to over 1 kg in 12 months and to 3 kg within 2 years (Schipp et al., 2007). The two largest Australian aquafeed manufacturers (located in Brisbane and Hobart) each produce a pellet feed that provides a specific diet promoting efficient growth and feed conversion. The industry relies heavily on these mills to provide a regular supply of high-quality feed. Cost of feed transport would be a major cost to barramundi production in the Southern Gulf catchments. As a carnivorous species, high dietary protein levels, with fishmeal as a primary ingredient, are required for optimal growth. Barramundi typically require between 1.2 and 1.5 kg of pelleted feed for each kilogram of body weight produced.

Warm water temperatures in northern Australia enable fish to be stocked in ponds year round. Depending on the intended market, harvested product is processed whole or as fillets and delivered fresh (refrigerated or in ice slurry) or frozen. Smaller niche markets for live barramundi are available for Asian restaurants in some capital cities.

Red claw

Water temperature and feed availability are the variables that most affect crayfish growth. Red claw are a robust species but are most susceptible to disease (including viruses, fungi, protozoa and bacteria) when conditions in the production pond are suboptimal (Jones, 1995). In tropical regions, mature females can be egg-bearing year round. Red claw breed freely in production ponds, so complex hatchery technology (or buying juvenile stock) is not required. However, low fecundity and the associated inability to source high numbers of quality selected broodstock are an impediment to intensive expansion of the industry. Production ponds are earthen, rectangular in design and on average 1 ha in size. They slope in depth from 1.2 to 1.8 m. Sheeting is used on the pond edge to keep the red claw in the pond (they tend to migrate), and netting surrounds the pond to protect stock from predators (Jones et al., 2000).

At the start of each crop, ponds are prepared (as for black tiger prawns above), then filled with fresh water and left for about 2 weeks before stocking. During this period, algal blooms in the water are encouraged through addition of organic fertiliser. Ponds are then stocked with about 250 females and 100 males that have reached sexual maturity. Natural mating results in the production of around 20,000 advanced juveniles. Red claw are omnivorous, foraging on natural production such as microbial biomass associated with decaying plants and animals. Early-stage crayfish rely almost solely on natural pond productivity (phytoplankton and zooplankton) for nutrition. As the crayfish progress through the juvenile stages, the greater part of the diet changes to organic particulates (detritus) on the bottom of the pond. Very small quantities of a commercial feed are added daily to assist with the weaning process and provide an energy source for the pond bloom. Providing adequate shelters (net bundles) is essential at this stage to improve survival (Jones, 2007). Approximately 4 months after stocking, the juveniles are harvested and graded by size and sex for stocking in production ponds.

Juveniles are stocked in production ponds at 5 to 10 per square metre. Shelters are important during the grow-out stage, with 250/ha recommended. During the grow-out phase, pellet feed becomes an important nutrition source, along with the natural productivity provided by the pond. Current commercial feeds are low cost and provide a nutrition source for natural pond productivity as much as for the crayfish. Most Australian farmers use diets consisting of 25% to 30% protein. Effective farm management involves maintaining water quality conditions within ranges optimal for crayfish growth and survival as pond biomass increases. As with barramundi, management involves increasing aeration and water exchanges, while strictly managing effluent discharges. Red claw are harvested within 6 months of stocking to avoid reproduction in the production pond. At this stage the crayfish will range from 30 to 80 g. Stock are graded by size and sex into groups for market, breeding or further grow-out (Jones, 2007).

Estimated water use

An average crop of prawns farmed in intensive pond systems (8 t/ha over 150 days) is estimated to require 127 ML of marine water, which equates to 15.9 ML of marine water for each tonne of harvested product (Irvin et al., 2018). For pond culture of barramundi (30 t/ha over 2 years), 562 ML of marine water, or fresh water, is required per crop, equating to 18.7 ML of water for each tonne of harvested fish. For extensive red claw culture (3 t/ha over 300 days), 240 ML of fresh water is required per pond crop, equating to 16 ML of water for each harvested tonne of crayfish (Irvin et al., 2018).

4.5.4 Aquaculture land suitability

The suitability of areas for aquaculture development was also assessed from the perspective of soil and land characteristics using the set of five land suitability classes in Table 4-1. The limitations considered include clay content, soil surface pH, soil thickness and rockiness. Limitations mainly relate to geotechnical considerations (e.g. construction and stability of impoundments). Other limitations, including slope, and the likely presence of gilgai microrelief and acid-sulfate soils, are indicative of more difficult, expensive and therefore less suitable development environments, and a greater degree of land preparation effort. More detail can be found in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Suitability was assessed for lined and earthen ponds, with earthen ponds requiring soil properties that prevent pond leakage. Soil acidity (pH) was also considered for earthen ponds, as some aquaculture species can be affected by unfavourable pH values exchanged into the water column (i.e. biological limitation). Two aquaculture species were selected to represent the environmental needs of marine species (represented by prawns) and freshwater species (red claw). Additionally, barramundi and other euryhaline species, which can tolerate a range of salinity conditions, may be suited to either marine or fresh water, depending on management choices. Except for aquaculture of marine species, which for practical purposes is restricted by proximity to sea water, no consideration was given in the analysis to proximity to suitable water for aquaculture of fresh and euryhaline species. It was not possible to include proximity to fresh water due to the large number of potential locations where water could be captured and stored within the catchments. Note also that the estimates for land suitability presented below represent the total areas of the catchments unconstrained by factors such as water availability, land tenure, environmental and other legislation and regulations, and a range of biophysical risks such as cyclones and flooding. These are addressed elsewhere by the Assessment. The land suitability maps are designed to be used predominantly at the regional scale. Planning at the enterprise scale would demand more localised assessment.

Analysis of suitability of land for marine aquaculture has been restricted to locations within 2 km of a marine water source. Marine aquaculture land suitability is shown in Figure 4-33 and presents suitability across the areas under tidal influence and river margins where cracking clay (SGG 9) and seasonally or permanently wet soils (SGG 3) dominate. These soils show the desired land surface characteristics such as no rockiness, suitable slope and sufficient soil thickness, but they have the risk of acid-sulfate soils and must be managed accordingly.

Suitable land for marine aquaculture in lined ponds (Figure 4-33a) totals 300,206 ha (2.8% of the catchments) and is restricted to the Karumba Plain physiographic unit where SGG 3 (seasonally or permanently wet) soils dominate, representing largely Class 2 land (86,000 ha, 0.8%). The suitable area extends into some of the most downstream areas of the Armraynald Plain physiographic unit, where tidal influence is still felt, and coincides with the presence of SGG 9 soils (cracking clays).

The land suitability patterns for marine species in earthen ponds (Figure 4-33b) closely mirror those of the marine lined ponds, although areas are restricted to slowly permeable cracking clay soils. Approximately 193,600 ha (1.8% of the catchments) is mapped as suitability Class 3, where the possibility for earthen ponds depends on soil factors including sufficient depth, low soil permeability and heavier surface textures.

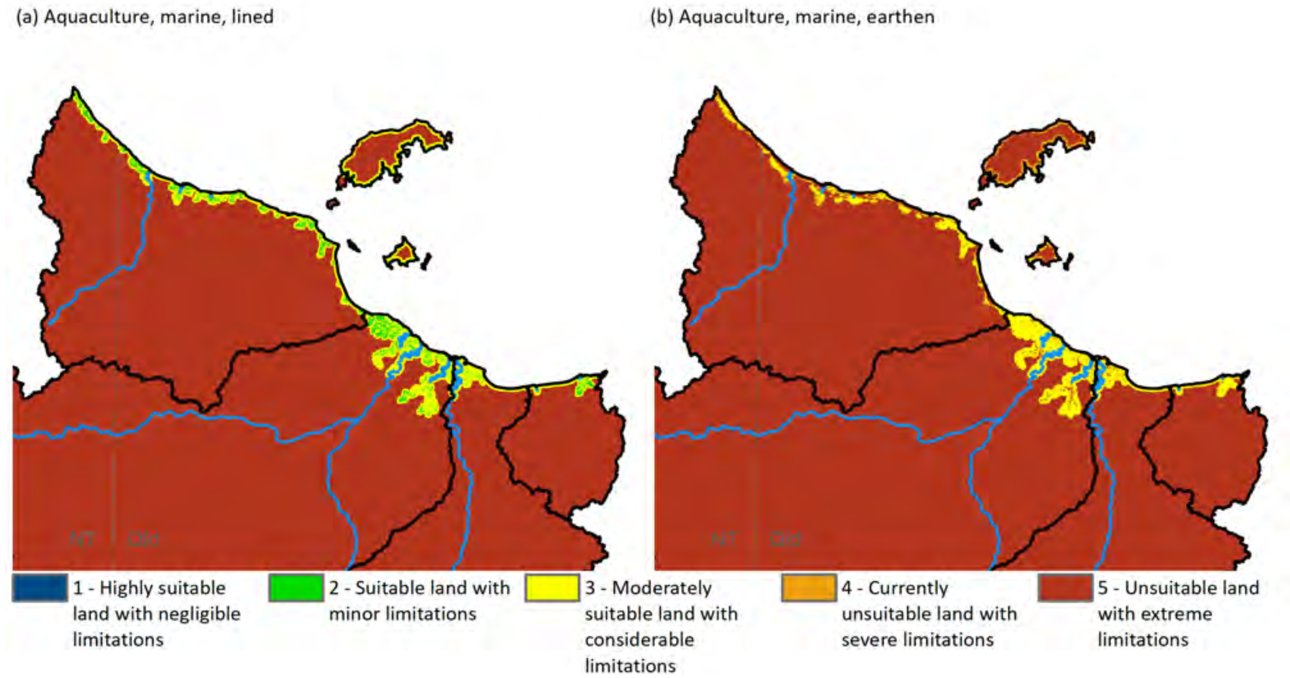

Figure 4-33 Land suitability in the Southern Gulf catchments for marine species aquaculture in (a) lined ponds and (b) earthen ponds

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the suitability data are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

The aquaculture land suitability analyses for freshwater species do not consider availability of fresh water for production, only soil and land attributes (Figure 4-34). This shows that a significant proportion of the catchments is suitable for freshwater aquaculture in lined ponds (6,265,400 ha, 57.9%; Figure 4-34a), with the unsuitable areas associated with higher slopes and shallow and/or rocky soils (SGG 7). The suitable area includes the low slope, deep and non-rocky parts of all SGGs except SGG 7, and the majority of the area is Class 2 (suitable with minor limitations) 5,154,300 ha (47.6%), with smaller proportions of Class 1 (40,300 ha, 0.4%) and Class 3 (1,070,800 ha, 9.9%).

In comparison, opportunities for freshwater species in earthen ponds in the Assessment area are more restricted: 2,408,273 ha (22.3%) of which only 170 ha is Class 2 (Figure 4-34b). Shallow and/or rocky (SGG 7) and moderately to highly permeable soils are unsuited to earthen water impoundments. The suitable areas match the cracking clay soils (SGG 9) distribution as these soils provide the necessary soil conditions including depth, slower permeability and clay textured surface soils. There are also significant areas on the Karumba Plain of slowly permeable seasonally or permanently wet (SGG 3) and cracking clay (SGG 9) soils. These coastal plains have potential acid-sulfate soils that would require appropriate management.

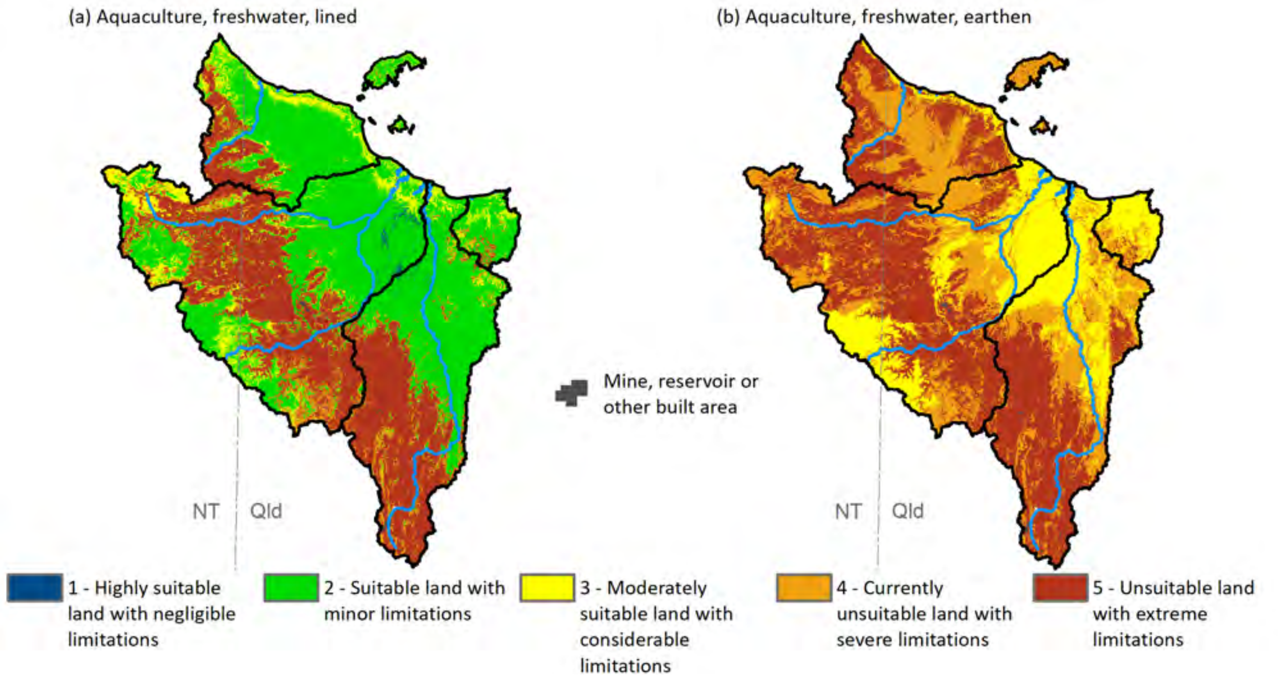

Figure 4-34 Land suitability in the Southern Gulf catchments for freshwater species aquaculture in (a) lined ponds and (b) earthen ponds

These land suitability maps do not consider flooding, risk of secondary salinisation or availability of water. The methods used to derive the suitability data are outlined in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

4.5.5 Aquaculture viability

This section provides a brief, generic analysis of what would be required for new aquaculture developments in the Southern Gulf catchments to be financially viable. First, indicative costs are provided for a range of four possible aquaculture enterprises that differ in species farmed, scale and intensity of production. The cost structure of the enterprises was based on established tools available from the Queensland Government for assessing the performance of existing or proposed aquaculture businesses (Queensland Government, 2024). Based on the ranges of these indicative capital and operating costs, gross revenue targets that a business would need to attain to be commercially viable are then calculated.

Enterprise-level costs for aquaculture development

Costs of establishing and running a new aquaculture business are divided here into the initial capital costs of development and ongoing operating costs. The four enterprise types analysed were chosen to portray some of the variation in cost structures between potential development options, not as a like-for-like comparison between different types of aquaculture (Table 4-26).

Table 4-26 Indicative capital and operating costs for a range of generic aquaculture development options

Costs are provided both per hectare of grow-out pond and per kilogram of harvested produce, although capital costs scale mostly with the area developed, and operating costs scale mainly with crop yield at harvest. Capital costs have been converted to an equivalent annualised cost assuming a 10% discount rate and that a quarter of the developed infrastructure was for 15-year life span assets and the remainder for 40-year life span assets. Indicative breakdowns of cost components are provided on a proportional basis.

PARAMETER	UNIT	PRAWN (EXTENSIVE)	PRAWN (INTENSIVE)	BARRAMUNDI	RED CLAW (SMALL SCALE)
Scale of development					
Grow-out pond area	ha	20	100	30	4
Total farm area	ha	25	150	100	10
Yield at harvest	t/y	30	800	600	32
Yield at harvest per pond area	t/ha/y	1.5	8.0	20.0	3.0
Capital costs of development (scale with area of grow-out ponds developed)					
Land and buildings	%	56	26	23	30
Vehicles	%	5	2	2	11
Pond-related assets	%	27	67	70	41
Other infrastructure and equipment	%	11	6	5	17
Total capital cost (year 0)	$/ha	74,000	142,000	147,000	163,000
Equivalent annualised cost	$/kg	5.41	1.94	0.81	5.95
	$/ha/y	8,108	15,558	16,106	17,859
Operating costs (vary with yield at harvest, except overheads)					
Nursery/juvenile costs	%	12	9	7	1
Feed costs	%	0	26	30	8
Labour costs	%	47	13	12	57
Electricity costs	%	16	24	30	9
Packing costs	%	2	4	3	2
Transport costs	%	6	16	16	11
Overhead costs (fixed)	%	17	8	1	12
Total annual operating costs	$/kg	19.31	12.47	12.46	17.80
	$/ha/y	28,966	99,783	249,211	53,402
Total costs of production					
Total annual cost	$/kg	24.72	14.42	13.27	23.75
	$/ha/y	37,100	115,300	265,300	71,300

Capital costs include all land development costs, construction, and plant and equipment accounted for in the year production commences. The types of capital development costs are largely similar across the aquaculture options, with costs of constructing ponds and buildings dominating the total initial capital investment. Indicative costs were derived from the case study of Guy et al. (2014), and consultation with experts familiar with the different types of aquaculture, including updating to December 2023 dollar values (Table 4-26).

Operating costs cover both overheads (which do not change with output) and variable costs (which increase as the yield of produce increases). Fixed overhead costs in aquaculture are a relatively small component of the total costs of production. Overheads consist of costs relating to licensing, approvals and other administration (Table 4-26).

The remaining operating costs are variable (Table 4-26). Feed, labour and electricity typically dominate the variable costs. Aquaculture requires large volumes of feed inputs, and the efficiency with which this feed is converted to marketed produce is a key metric of business performance. Labour costs consist of salaries of permanent staff and casual staff who are employed to cover intensive harvesting and processing activities. Aerators require large amounts of energy, increasing as the biomass of produce in the ponds increases, which accounts for the large costs of electricity. Transport, although a smaller proportional cost, is important because this puts remote locations at a disadvantage relative to aquaculture businesses that are closer to feed suppliers and markets. In addition, transport costs may be higher at times if roads are cut (requiring much more expensive air freight or alternative, longer road routes) or if the closest markets become oversupplied. Packing is the smallest component of variable costs in the breakdown categories used here.

Revenue for aquaculture produce typically ranges from $10 to $20 per kg (on a harvested mass basis), but prices vary depending on the quality and size classes of harvested animals and how they are processed (e.g. live, fresh, frozen or filleted). Farms are likely to deliver a mix of products targeted to the specifications of the markets they supply. Note that the mass of sold product may be substantially lower than the harvested product (e.g. fish fillets are about half the mass of harvested fish), so prices of sold product may not be directly comparable to the costs of production in Table 4-26, which are on a harvest mass basis.

Commercial viability of new aquaculture developments

Capital and operating costs differ between different types of aquaculture enterprises (Table 4-27), but these costs may differ even more between locations (depending on case-specific factors such as remoteness, soil properties, distance to water source and type of power supply). Furthermore, there can be considerable uncertainty in some costs, and prices paid for produce can fluctuate substantially over time. Given this variation among possible aquaculture developments in the Southern Gulf catchments, a generic approach was taken to determine what would be required for new aquaculture enterprises to become commercially viable. The approach used here was to calculate the gross revenue that an enterprise would have to generate each year to achieve a target internal rate of return (IRR) for given operating costs and development costs (both expressed per hectare of grow-out ponds). Capital costs were converted to annualised equivalents on the assumption that developed assets equated to a mix of 25% 15-year assets and 75% assets with a 40-year life span (using a discount rate matching the target IRR). The target gross revenue is the sum of the annual operating costs and the equivalent annualised cost of the infrastructure development (Table 4-27).

Table 4-27 Gross revenue targets required to achieve target internal rates of return (IRR) for aquaculture developments with different combinations of capital costs and operating costs

All values are expressed per hectare of grow-out ponds in the development. Gross revenue is the yield per hectare of pond multiplied by the price received for produce (averaged across products and on a harvest mass basis). Capital costs were converted to an equivalent annualised cost assuming a quarter of the developed infrastructure was for 15-year life span assets and the remainder for 40-year life span assets. Targets would be higher after taking into account risks such as initial learning and market fluctuations.

OPERATING COSTS ($/ha/y)	GROSS REVENUE REQUIRED TO ACHIEVE TARGET IRR ($/ha/y)								
	Capital costs of development ($/ha)								
	60,000	**70,000**	**80,000**	**90,000**	**100,000**	**110,000**	**125,000**	**150,000**	**175,000**
7% target IRR									
20,000	25,022	25,859	26,696	27,533	28,371	29,208	30,463	32,556	34,648
50,000	55,022	55,859	56,696	57,533	58,371	59,208	60,463	62,556	64,648
100,000	105,022	105,859	106,696	107,533	108,371	109,208	110,463	112,556	114,648
150,000	155,022	155,859	156,696	157,533	158,371	159,208	160,463	162,556	164,648
200,000	205,022	205,859	206,696	207,533	208,371	209,208	210,463	212,556	214,648
250,000	255,022	255,859	256,696	257,533	258,371	259,208	260,463	262,556	264,648
10% target IRR									
20,000	26,574	27,669	28,765	29,861	30,956	32,052	33,695	36,434	39,174
50,000	56,574	57,669	58,765	59,861	60,956	62,052	63,695	66,434	69,174
100,000	106,574	107,669	108,765	109,861	110,956	112,052	113,695	116,434	119,174
150,000	156,574	157,669	158,765	159,861	160,956	162,052	163,695	166,434	169,174
200,000	206,574	207,669	208,765	209,861	210,956	212,052	213,695	216,434	219,174
250,000	256,574	257,669	258,765	259,861	260,956	262,052	263,695	266,434	269,174
14% target IRR									
20,000	28,776	30,238	31,701	33,163	34,626	36,089	38,283	41,939	45,596
50,000	58,776	60,238	61,701	63,163	64,626	66,089	68,283	71,939	75,596
100,000	108,776	110,238	111,701	113,163	114,626	116,089	118,283	121,939	125,596
150,000	158,776	160,238	161,701	163,163	164,626	166,089	168,283	171,939	175,596
200,000	208,776	210,238	211,701	213,163	214,626	216,089	218,283	221,939	225,596
250,000	258,776	260,238	261,701	263,163	264,626	266,089	268,283	271,939	275,596

In order for an enterprise to be commercially viable, the volume of produce grown each year multiplied by the sales price of that produce would need to match or exceed the target values provided above. For example, a proposed development with capital costs of $125,000/ha and operating costs of $200,000 per ha per year would need to generate gross revenue of $213,695 per ha per year to achieve a target IRR of 10% (Table 4-27). If the enterprise received $12/kg for produce (averaged across product types, on a harvest mass basis), then it would need to sustain mean long-term yields of 18 t/ha (= $213,695 per ha per year ÷ $12/kg × 1 t/1000 kg) from the first harvest. However, if prices were $20/kg, mean long-term yields would require 11 t/ha (= $213,695 per ha per year ÷ $20/kg × 1 t/1000 kg) for the same $125,000 capital costs per hectare, or only 6 t/ha harvests if the capital costs decreased to $100,000 per hectare. Target revenue would be higher after taking into account risks such as learning and adapting to the particular challenges of a new location, and periodic setbacks that could arise from disease, climate variability, changes in market conditions or new legislation.

Key messages

From this analysis, a number of key points about achieving commercial viability in new aquaculture enterprises are apparent:

- Operating costs are very high, and the amount spent each year on inputs can exceed the upfront (year zero) capital cost of development (and the value of the farm assets). This means that the cost of development is a much smaller consideration for achieving profitability than ongoing operations and costs of inputs.
- High operating costs also mean that substantial capital reserves are required, beyond the capital costs of development, as there will be large cash outflows for inputs in the start-up years before revenue from harvested product starts to be generated. This is particularly the case for larger size classes of product that require multi-year grow-out periods before harvest. Managing cashflows would therefore be an important consideration at establishment and as yields are subsequently scaled up.
- Variable costs dominate the total costs of aquaculture production, so most costs will increase as yield increases. This means that increases in production, by itself, would contribute little to achieving profitability in a new enterprise. What is much more important is increasing production efficiency, such as feed conversion rate or labour efficiency, so inputs per unit of produce are reduced (and profit margins per kilogram are increased).
- Small changes in quantities and prices of inputs and produce would have a relatively large impact on net profit margins. These values could differ substantially between different locations (e.g. varying in remoteness, available markets, soils and climate) and depend on the experience of managers. Even small differences from the indicative values provided in Table 4-27could render an enterprise unprofitable.
- Enterprise viability would therefore be very dependent on the specifics of each particular case and how the learning, scaling up and cashflow were managed during the initial establishment years of the enterprise. It would be essential for any new aquaculture development in the Southern Gulf catchments to refine the production system and achieve the required levels of operational efficiency (input costs per kilogram of produce) using just a few ponds before scaling any enterprise.

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