Agricultural Systems 155 (2017) 116–125

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Irrigated agricultural development in northern Australia: Value-chain challenges and opportunities

Andrew Ash[a,*], Trish Gleeson[b], Murray Hall[c,d], Andrew Higgins[c], Garry Hopwood[a], Neil MacLeod[a], Dean Paini[e], Perry Poulton[a], Di Prestwidge[a], Tony Webster[a], Peter Wilson[c]

[a] CSIRO Agriculture and Food, Australia
[b] Australian Bureau of Agricultural and Resource Economics and Sciences, Australia
[c] CSIRO Land and Water, Australia
[d] Present address: The University of Queensland, Australia
[e] CSIRO Health and Biosecurity, Australia

ABSTRACT

There is renewed interest in expanded agricultural development in northern Australia supported by increasing global demand for food, the region's proximity to Asian markets, and the current government policy initiatives to support economically sustainable and vibrant rural and regional communities. The production potential, financial returns, and the supply chain implications for irrigated agriculture were assessed in four different regions across northern Australia to provide a systems analysis of development opportunities and challenges. Gross margins for high volume, low value broadacre crops were mostly either negative or weakly positive, principally due to high transport costs to established markets in southern and eastern Australia. The returns were largely positive for higher value horticultural and specialist niche crops or industrial crops with local processing facilities. Scenarios incorporating alternative transport routes to Asia provided modest cost savings, but required assumptions for suitable shipping routes and cost-effective availability of containers, but did not significantly boost gross margins. When scaled to whole irrigation areas, the regional gross value of production could be significant but improving returns at farm scale requires more cost-effective supply chains. The ability to generate sufficient returns on capital investment was strongly influenced by the sequence of years associated with climatic variability and/or other unexpected shocks experienced in the years immediately following investment. The analysis highlighted that each component of the system – climate, soils, water, agronomic practice, pests and diseases, farm operations, management, planning, supply chains, infrastructure, labour, services, markets – needs to be understood but ultimate success will depend on managing the complexity of the whole farming system and value-chain. Further, scaling up development at a considered pace and being prepared for considerable lags before positive returns on investment are achieved will be critical for successful long-term irrigated agricultural ventures in northern Australia.

1. Introduction

Agricultural development in northern Australia has been variously described as the last frontier, the new frontier and the next frontier. All of these epithets convey a sense that this vast area north of the Tropic of Capricorn, comprising around 40% of Australia's land mass and < 5% of the national population, is waiting to be developed. Indeed, for well over a century there has been a succession of public and private initiatives to either promote or initiate intensive agriculture in northern Australia to complement the well-established extensive beef cattle industry and support a larger population and regional economy. These development initiatives have met with mixed fortunes, some ending in disappointment and dashed hopes (Cook 2009; Pearson and Gorman 2010), while others have been successful and continue today (Ash, 2014).

Increased interest in agricultural development for northern Australia is being driven by a number of apparent opportunities. These include the proximity to Asian markets that are growing in both size and prosperity (Reardon and Timmer 2014), increasing global demand for food and natural fibre and its implications for food security (FAO 2009), and the development of economically sustainable and vibrant regional communities (Anon 2014).

* Corresponding author.
E-mail address: andrew.ash@csiro.au (A. Ash).

http://dx.doi.org/10.1016/j.agsy.2017.04.010
Received 9 December 2016; Received in revised form 14 March 2017; Accepted 27 April 2017
0308-521X/

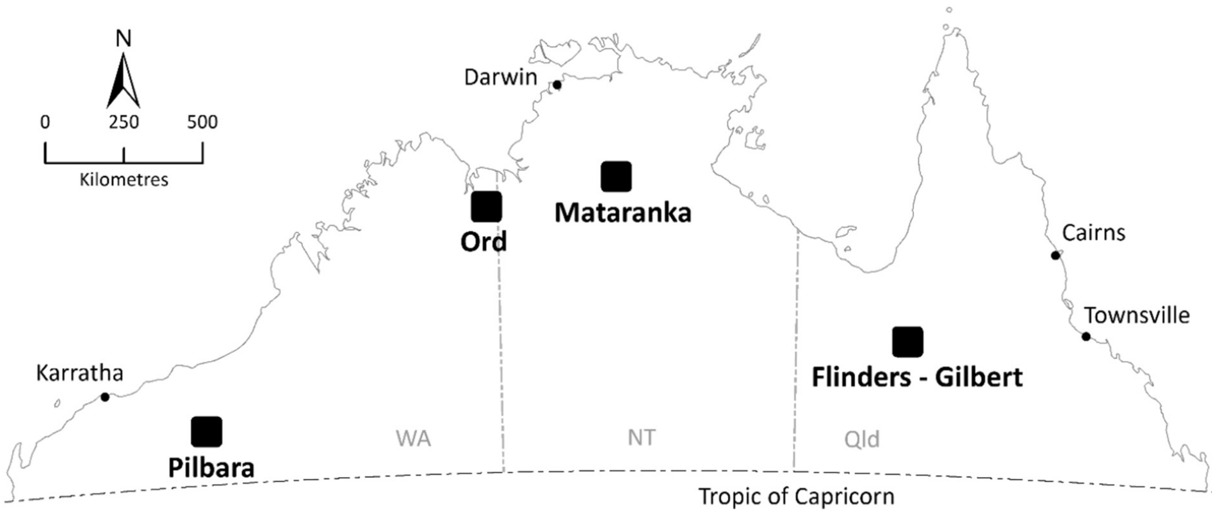

Fig. 1. Map showing the four study regions (denoted by squares) in northern Australia.

Direct challenges facing expanded agricultural development in northern Australia include:

- accessing suitable land and water resources to underpin expanded agricultural production
- navigating the various approval processes associated with land tenure, Native Title, water resource plans, environmental impact etc.
- sourcing the significant capital investment required to support the high cost of 'greenfields' agricultural development
- cost-effectively, reliably and sustainably growing agricultural products in the northern tropical environment and getting them to market via efficient supply chains
- establishing new and viable export markets for high-value, perishable fruit and vegetable products with high seasonality of supplies
- maintaining the ecological values of northern Australia.

Successfully addressing these challenges is critical to establishing the value proposition for northern agricultural expansion. Efficient agricultural systems, infrastructure and food supply chains are paramount for growing a productive and competitive agricultural sector to seize opportunities from changing patterns in global food consumption, and particularly in growing markets in Asia (Regional Australia Institute 2013).

The north Australian environment provides some particular opportunities and challenges for intensive agricultural development. The climate provides a comparative advantage for growing tropical fruits and vegetables compared with the temperate regions of southern Australia. More than 70 years of agronomic research has been applied to a wide range of crops suitable for northern conditions (Chapman et al. 1996). Apart from the considerable body of work on individual crops there was also a focussed effort over two decades on dryland farming systems, involving crop and ley pasture rotations (McCown 1996). This work was aimed at both maintaining soil fertility and health and understanding the role of crop rotations for increasing yields and returns. However, there has been relatively little research effort directed to crop rotations in irrigated agriculture in northern Australia, except for work on legume rotations in sugar cane (Garside and Bell 2011).

Expanded cropping development over much of northern Australia will be largely dependent on irrigation. This is because most of the annual rainfall occurs over a relatively short wet season and there is considerable year-to-year variability in both the duration of the wet season and the annual rainfall total. When these climatic constraints are combined with soil and agronomic management challenges in the semi-arid tropics (McCown 1996) then dryland farming systems are likely to be opportunistic rather than mainstream. As a consequence, there has been no significant expansion of dryland cropping in tropical Australia in the last two decades.

While the major rivers of northern Australia can deliver large quantities of water that is nominally suitable for irrigation, the flows are strongly seasonal and the water is not always available in the best locations for siting intensive agriculture, nor are there many options for cost-effective storage and distribution of water (Petheram et al. 2008). Nevertheless, there are opportunities for significant scale irrigation development in different locations across northern Australia with a total estimated irrigation potential of 1.4 million ha from surface water storage (Petheram et al. 2014).

The scope of this potential contrasts with the actual established area of irrigated agriculture in northern Australia of only approximately 150,000 ha (ABS 2016, WA Department of Agriculture and Food: https://www.agric.wa.gov.au/assessment-agricultural-expansion/ord-river-development-and-irrigated-agriculture). This area is comprised of: 119,000 ha in Qld, mostly in the Burdekin and Mareeba-Dimbulah Irrigation Areas and serviced by large dams; 5000 ha in the Top End of the Northern Territory, largely using groundwater sources; and 30,000 ha in Western Australia, the vast majority which occurs in the Ord River Irrigation Area (Ord Stages 1 and 2) drawing water from Lake Argyle, and some small scale ground-water based irrigation in the West Kimberley region.

With these opportunities and challenges as context, we examined both the production potential and the supply chain implications for irrigated agricultural development opportunities in four different regions across northern Australia. While there has been considerable past agronomic work undertaken on the potential for individual crops and forages in northern Australia this has been in isolation from the dependent supply chains.

2. Methods

The study was centred on four regional case studies (Fig. 1):

- Ord River Irrigation Area, including expansion into the Northern Territory
- Katherine-Mataranka region of the Northern Territory
- Pilbara region in Western Australia, with a focus on water available through mine de-watering
- Flinders and Gilbert Rivers region of north Queensland

For each of these regional case studies, a range of issues were examined that were judged to be important for successful agricultural development:

(a) Agricultural potential was assessed by examining the climate in each region and determining the production potential for a range of crops, including crops that are already grown in existing irrigation areas, using both simulation modelling and observed production.
(b) Farm-scale financial implications were assessed by undertaking gross margin analyses for a wide range of crops, tailored to each region. This drew on both existing data and new analyses for crops that are not presently grown in the case study regions, or are presently grown on a very limited scale.
(c) Supply chain logistics for transport and non-transport related infrastructure (storage, processing facilities, power, water) for cropping in each of the regions was assessed for both existing and new markets, using newly developed supply chain models.
(d) Regional scale assessment. Two contrasting scenarios of scaled-up production were developed for each region to examine the regional implications for agricultural development. Practical investment priorities to improve the productivity and competiveness of fibre and food supply chains were identified, as were linkages and synergies between different agricultural commodities.

Sequences of years in terms of climate variability, market shocks, extreme weather events or pest and disease outbreaks may have a significant impact on financial success, especially in the early years following capital investment. The impact of such events was assessed using some simple scenarios.

(a) Agricultural potential
Climate

Historical rainfall data was sourced from the SILO rainfall database, which is administered by the Queensland Government (www.longpaddock.qld.gov.au — Jeffrey et al. 2001). The data that were used as inputs to simulation modelling and analysis included rainfall, evaporation, radiation, vapour pressure, and maximum and minimum temperature for climate stations in each of the regions.

Soils and land suitability

Northern Australian soils and their characteristics are generally well known from past surveys (e.g. Christian and Stewart 1953; Biggs and Philip 1995; Schoknecht and Grose 1996) but relatively few are mapped at a sufficiently fine scale to inform individual developments. Detailed investigations have been undertaken recently in several developing agricultural areas, such as the Ord River in Western Australia, Daly Basin in the Northern Territory, and the Flinders and Gilbert Rivers in Queensland (e.g. Bartley et al. 2013) but while these studies better inform the general suitability for development they are also not at fine enough scale for individual developments.

Based on the approach of Wilson et al. (2013), a broad land suitability framework across the north of Australia was applied using the best available and nationally consistent soil data, drawing on data from the various surveys described above, that is collated within the Australian Soil Resource Information System (ASRIS 2014). These frameworks assess a particular cropping enterprise (such as irrigated annual crops, perennial crops or forestry) and the necessary management considerations, based on the known limitations of the soil and land resources (e.g. soil depth, texture, rockiness, land slope or erodibility).

Crop production

The range of crops included in the case studies included those already grown in the particular region, crops that are presently grown in other northern regions and crops that may be suited to northern Australia but have yet to be commercially proven there. From these options, crops were selected for review after consultation with regional stakeholders or individuals and groups who have a responsibility for crop research, development and extension within state or territory jurisdictions.

For each region, the crops selected for review included at least one crop from each of the categories of broadacre food, horticulture or industrial crops. A forage crop for hay production was also included for two of the regional case studies. The selected crops by regions are shown in Table 1.

The APSIM crop yield simulation model (Keating et al. 2003) was used to project yields for the range of broadacre food and industrial crops for which specific crop models were available, including chickpea, mungbean, peanut, soybean, maize, sorghum, forages, sugarcane, cotton and rice. Within each region, historical daily climate records over a 50 year period (1960 to 2010), characteristics of representative soils (e.g. physical structure, water-holding capacity and nutrient levels), and appropriate agronomic and management practices were used to parameterise APSIM. A range of other broadacre crops were assessed for which APSIM models are yet to be calibrated or tested. These crops included chia, hemp, sandalwood, cassava, and poppy. Yields from experimental and commercial plantings were used to estimate production for these crops, and, where there was no field data, published estimates were also used.

There is currently no modelling capability available in the APSIM framework for the horticultural crops that were considered for this study (banana, cucurbits and mango). Estimates of the yield for these crops in each region were based on reported production from commercial and experimental plantings in northern Australia.

Table 1
Crops assessed within each of the four case study regions.

Crop	Flinders & Gilbert	Ord	Pilbara	Mataranka
Broadacre food				
Rice	X	X		
Sorghum/maize	X	X	X	X
Chickpea/mungbean	X	X	X	X
Peanut (groundnut)	X	X	X	X
Chia	X	X		
Horticulture				
Mango	X	X		X
Banana	X	X		
Cucurbits		X	X	X
Industrial/forages/other				
Sugarcane (raw sugar)	X	X		
Cotton (fibre, protein source)	X	X	X	X
Hemp (fibre)	X	X		
Sandalwood (oils)	X	X		X
Guar (industrial substrates)	X		X	
Poppy (medicinal drug)				X
Cassava (biofuel)	X			
Forage sorghum (forage)	X		X	
Lablab forage (forage)			X	

(b) Farm scale financial analysis

The approach used in this study to assess financial outcomes of various development options was primarily based on gross margin analysis (Malcolm et al. 2005). The first stage involved the collation of *baseline gross margin* (total sales revenue less direct production, marketing and transport costs[1]) estimates for an array of field, horticultural and plantation crops for each of the study regions. These gross margin estimates were calculated for a *representative* synthetically constructed

[1] The production costs include processing and preparation for transport and marketing for crops that are sold ex-farm in a form that is principally ready for final consumption (e.g. packed cartons of horticultural produce). The costs of shipping and marketing included in the gross margin estimates may also include elements of preparation for export including meeting quarantine and other protocols for overseas markets.

farm (i.e. typical of the scale and structure of the local farming system, climate and resources) assumed to be located in the region and are presented on a *gross margin per hectare* basis. The second stage involved creating *scenarios* of irrigation development opportunities (Table 3) and making assumptions concerning projected changes in either the input costs or output prices for the different crops or the technical efficiency (input-output ratios) with which they are grown.

Templates were created for calculating the individual crop gross margins and adapted to meet the particular characteristics of a given crop in each region. Information to populate the templates was collected from published data and through interactions with economists and agronomists located in each of the study regions. This approach was supplemented by collating a mix of computer simulated crop yield, input cost and output price data that were drawn from archival sources, trade publications, technical advice sourced from public and private technical experts, and local agribusiness operations.

Variability in gross margins was explored by using the variability in crop yields as well as historical variation in crop prices. The resulting distribution of gross margins was used to show the likelihood and severity of good and bad years compared with the most likely result. This builds on a single number estimate to reflect the chance of better and poorer years.

(c) Supply chains and logistics

A supply chain model was developed to identify the logistics costs for each crop by region and to evaluate infrastructure opportunities or restrictions. The scope of the supply chain analysis was between farm gate (postharvest) and the port or distribution centre. Depending on the crop, the supply chain paths will vary in terms of segments (transport, processing, storage) and destinations, as illustrated schematically in Fig. 2.

The Transport Network Strategic Investment Tool (TraNSIT) (Higgins et al. 2015) was used to create the supply chain for each regional case study and crop, to determine the logistics costs per tonne of product handled or for the whole case study region. While, TraNSIT is largely focused on transport costs, the other major supply chain cost elements of processing, packaging and storage were included where data were available. When benchmarked against some actual transport costs that were paid by a selection of livestock, mango and grains producers, the modelled costs were within 10% for longer trips (> 250 km).

Very low volumes of agricultural products are shipped from northern Australia by sea transport, with sugar on the east coast being a notable exception. There is also a small volume of refrigerated containers arriving at northern ports and this creates a barrier for export of products requiring refrigeration. A combination of low shipping volumes and the current high cost of re-locating empty refrigerated containers to northern ports such as Darwin provided challenges for developing realistic costings for containerised and bulk agricultural commodities in the supply chain scenarios. Based on discussions with freight companies and shipping lines, costings were developed on the assumption of increased volumes and ready availability of refrigerated containers for shipping horticultural commodities.

(d) Regional scale assessment

Regional development scenarios were developed for each case study region for crop production at a scale that was based on the hectares of suitable land that could feasibly be supported by available water resources. For some regional case studies (e.g. Ord River Irrigation Area, Katherine-Mataranka) the amount of available water was based on specific water allocation plans, while in other case studies (e.g. Flinders and Gilbert region) the estimates were based on the best available information of the potential water availability (Petheram et al. 2013a, 2013b). These regional-scale water availability and use scenarios are summarised in Table 2.

The assumed scale of irrigation development varied considerably across the case study regions. For example, the Ord River Irrigation Area draws on a large and reliable water storage (Lake Argyle), with

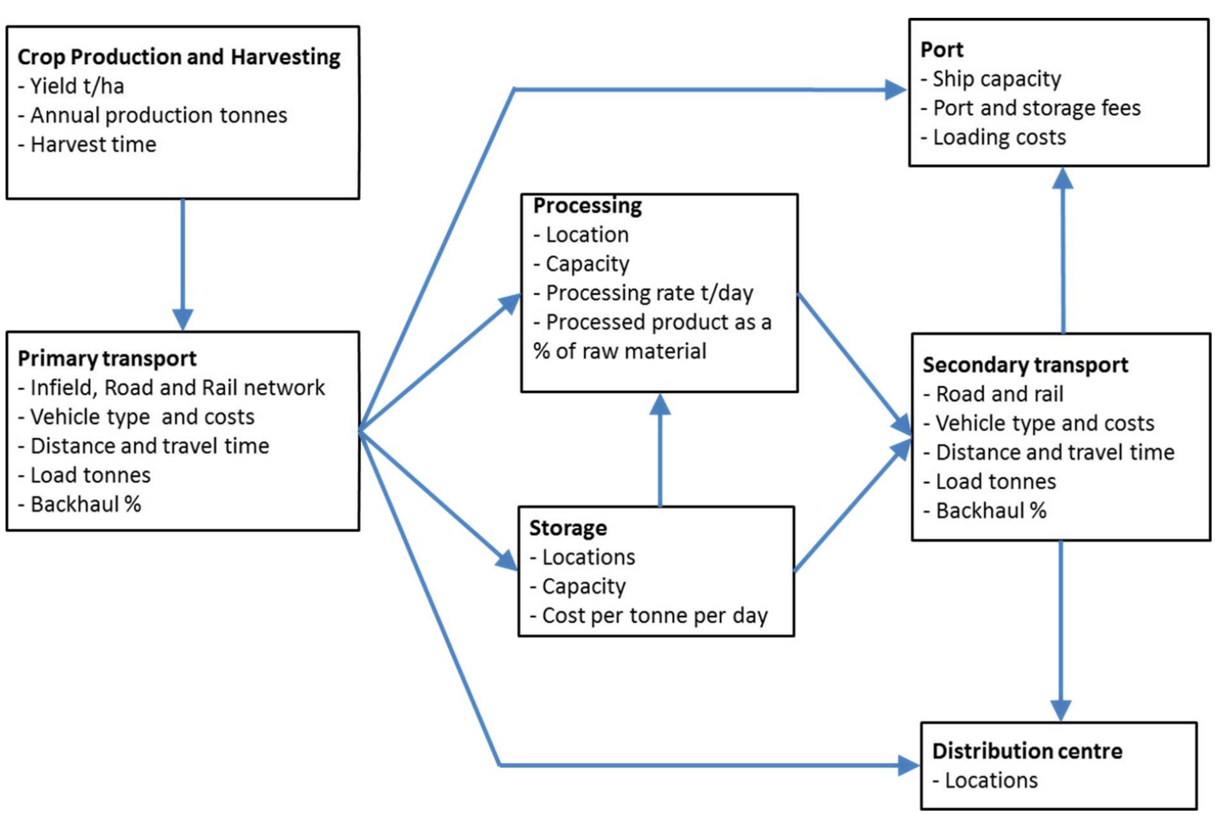

Fig. 2. Schematic outline of supply chain model and main variables.

Table 2
Scale of irrigation developments within the different regions used to assess aggregated outcomes.

Region	Water available for allocation (Gl)[a]	Annual reliability (%)	Development area (Ha)	Approximate water use (Ml/Ha)[b]
Pilbara[c]	120; groundwater	95	8000	10–15
Ord	865; surface water	95[d]	50,000	5–15
Mataranka	18[e]; groundwater	90 (5 GL; high) 70 (13 GL; medium)	2500	5–8[f]
Gilbert	300; surface water	85	30,000	5–12
Flinders	250; surface water	70–80	15,000	5–12

[a] Water available at the farm gate; does not include on farm losses.
[b] Assumes some water losses associated with field application.
[c] Potentially > 250 GL is available, but given the spatially diverse nature of the resource, temporal limits on availability of surplus mine water (i.e. finite limit to ore extraction operations that supply the water) and likelihood that not all mine de-water will be available, a conservative approach to water resource availability has been assumed.
[d] Even in the 5% years that are not 100% reliable, it is likely that > 50% water will be available.
[e] The upper limit of allocation is 36 GL but, beyond 18 GL, reliability becomes low.
[f] Assumes dominant use by horticulture, with lower water use and higher efficient methods (e.g. trickle/tape).

865 GL of water available for irrigation within the current water allocation plans. By contrast, the Tindall aquifer at Mataranka is a much smaller water resource (18 GL) and only capable of servicing around 2500 ha of additional irrigated land per year.

Two contrasting irrigation cropping development scenarios were created for each case study region on the basis of utilising the whole irrigation area as set out in Table 2. There were two broad groupings of cropping opportunities: one set of development scenarios was focused on mixed cropping or horticulture and, where appropriate, explored their export potential to Asia assuming improved shipping routes, supply chain logistics and necessary export protocols in place; while a second set of development scenarios focussed more on the effect of establishing new processing infrastructure at local scales to service a particular broadacre food or industrial crop (Table 3). From these scenarios, the gross value of production was calculated based on yield and price estimates from the gross margin analysis.

(e) Sequences of years and extreme events

Even with access to reasonably reliable water, irrigated crop production can be affected by extreme events, which can be related to weather, an unexpected pest or disease outbreak, or changing market conditions. Using irrigated cotton grown on an Ord River farm as an example, to assess the vulnerability of an enterprise to yield risk an assessment was carried out on the ability to service capital debt assuming three different sequences of years (below median yield, above median yield, two crop failures) in the ten years following the original capital investment in an irrigation development. The first and second sequences assumed a run of below median yield years and above median yield years in the first half of the 10-year sequence even though both sequences used overall the same ten individual years. The third sequence, used to simulate unexpected extreme events, included two crop failures as a result of extreme events (defined as receiving 20% of median yield) occurring randomly within the 10-year period of analysis. The analysis for each 10 year sequence was based on two levels (low, medium) of starting capital debt (AU$8000/ha or AU $12,000/ha), respectively representing typical levels of investment to develop land from largely undisturbed savanna or purchase previously developed land, and the ensuing crop gross margin returns were used to reduce (or increase) this capital debt. Interest rates were assumed to be 7%. This simple analysis was employed to highlight the impact of yield variability on the projected outcomes and did not represent a full financial cash flow analysis because overhead costs were not considered.

3. Results

Based on existing supply chains, the estimated gross margins (per hectare) for a range of broadacre, high value and industrial crops ranged from highly negative to highly positive (Table 4). Poor gross margins were more common for high volume, low value crops and industrial crops where distances to market or processing facilities were

Table 3
Cropping scenarios used in the analysis of the entire irrigation scheme within each region.

Region	Scenario 1 — mixed cropping and/or horticulture + export opportunities	Scenario 2 — mixed cropping + local processing facilities
Ord	Crops grown — rice, sandalwood, maize, mungbean, rockmelons, mangoes, chia. Assumptions — rice mill present, maize exported by ship from Wyndham to Surabaya (East Java, Indonesia), melons and mangoes exported vis ship from Wyndham assuming improved shipping and supply chain logistics, all other crops transported by road to southern Australia (> 3000 km)	Crops grown — sugar, cotton, mungbeans, sandalwood, rockmelons, chia. Assumptions — sugar mill and cotton gin in place, power to cotton gin provided by co-generation from sugar mill. Sugar exported via sea from Wyndham, other crops by road transport to southern Australia (> 3000 km).
Mataranka	Crops grown — watermelons, mangoes Assumptions — transported to Asia via ship out of Darwin, assuming better developed shipping routes and supply chain logistics than currently exists	Crops grown — maize, peanuts, watermelons, mangoes. Assumptions — maize incorporated into beef feeding systems within region, peanut dryer and shelling plant in place, horticultural crops transported south by road (> 2000 km).
Flinders Gilbert	Crops grown — maize, sorghum, peanuts, mangoes, cotton, hay. Assumptions — peanuts transported to existing processing plant on the Atherton Tableland (300 km), cotton gin in place in Charters Towers (450 km), mangoes exported via Cairns (380 km), other crops processed or used on the Atherton Tablelands	Crops grown — rice, sorghum, chickpeas, mungbeans, soybeans, sugarcane, hay. Rice and chickpeas double cropped. Assumptions — sugar mill in place in Gilbert region, rice processed in existing mill in Townsville (500 km), other crops processed or used on Atherton Tablelands or Townsville.
Pilbara	Crops grown — maize, peanuts, forage sorghum. Maize and peanuts double cropped. Assumptions — maize and forage sorghum used within region in beef feeding systems, peanuts transported by road to Perth (1500 km).	Crops grown — Mungbeans, cotton, guar, lablab hay. Mungbeans, guar, lablab double cropped with cotton. Assumptions — cotton gin in place, guar and lablab hay used as a rotation crop with cotton. Hay used within region, guar sent to Perth (1500 km) for processing.

Table 4
Variation in yield, gross margin and freight costs for a range of crops across the four study regions.

Crop	Yield	Price received (AU$)	Gross margin (AU $/ha)	Freight % of value
Broadacre				
Rice	8.3–10.7 t/ha	350/t	− 780–1150	18–58
Sorghum	8.4–9.1 t/ha	240/t	− 930–30	20–63
Maize	9.9–12.0 t/ha	280/t	− 450–350	25–54
Chickpea	2.4–2.8 t/ha	900/t	20–550	10–26
Mungbean	2.0–2.6 t/ha	925/t	1309–540	6–16
Peanut	4.7–5.3 t/ha		− 310–990	6–49
Chia	1.1 t/ha	3000/t	840–1190	8–9
Horticulture				
Mangoes	600–3100 trays (7 kg)/ha	22/tray	− 80–11,100	8–10
Bananas	2000–3000 cartons (13 kg)/ha	19/carton	6200–13,730	17–18
Watermelons	30–55 t/ha	900/t	− 4100–10,100	24–27
Rockmelons	1400–1700 trays (17 kg)/ha	19/tray	4900–6100	21–22
Industrial/other				
Sugarcane	110–120 t/ha	36/t	1310–1,370[a]	11–15
Cotton	2.0–2.1 t/ha	2200/t	− 1620–1220	15–57
Sandalwood	315 kg/ha oil	3500/kg	64,960–65,290	0.02–0.4

[a] Assumes that a sugar mill is located within the region of production.

significant. This featured more frequently in the Western Australia and Northern Territory regions (Pilbara, Ord, Mataranka) where distances to southern markets by road transport are between 1500 and 3000 km. For high volume, low value crops the transport costs accounted for over half of the total value of production, which generated large negative gross margins. In the Flinders-Gilbert region in Queensland the markets on the east coast were much closer (c. 400 km) and transport costs represented a much lower percentage of the value of production. Chia was an exception to these results because the relatively high value (c. $3000/t) of this crop resulted in freight costs representing less than one tenth of the value of production.

Horticultural crops generally returned high gross margins but the values were also very sensitive to price fluctuations associated with supply and demand and variability in production. Unlike broadacre crops where significant price movements occur over many months, prices for horticultural produce can vary significantly over days and weeks. For example, over the course of the 2013 calendar year wholesale prices varied from $14–$25/tray for bananas, $12–$60/tray for mangoes, and $11–$22/tray for rockmelons (data supplied by Ausmarket Consultants, Brisbane). The sensitivity of gross margins to price fluctuations is highlighted for the Ord Region in Table 5.

Sandalwood, which is harvested for its high value oil used in the pharmaceutical and cosmetic industries, generated the highest gross margins, almost by an order of magnitude. Reasonably conservative estimates of yield and price (using current prices) were used in the analysis and highlights the potential returns for a niche product that has limited global production and an increasing demand.

Table 5
Gross margin sensitivity (AU$/ha) to price of horticultural crops in the Ord region.

Price sensitivity: % variation from baseline	Mango — Kensington Pride	Banana	Watermelon	Rockmelon
− 45%	–$5209	–$10,798	–$5379	–$6477
− 30%	–$3499	–$5128	–$2211	–$2286
− 15%	–$1789	$542	$957	$1906
Baseline (0%)	–$79	$6211	$4125	$6097
+ 15%	$1631	$11,882	$7293	$10,288
+ 30%	$3340	$17,553	$10,461	$14,479
+ 45%	$5051	$23,222	$13,629	$18,670

Given the significance of freight costs in influencing the profitability of most crops grown in northern Australia, an important part of the analysis was to examine how gross margins might be improved by developing more cost-effective supply chains (Table 6). Developing closer markets had a large positive influence on most broadacre crops with an exception being for maize shipped from the Pilbara region to Asia, which reduced gross margins compared with road freight to Perth. The largest increase in gross margin was observed for siting processing facilities locally for industrial crops such as cotton. This result is not surprising as the success of these crops in established cropping areas in Australia is dependent on access to local processing facilities. The gross margins did not include any costs associated with the capital expenditure on the processing facilities, which can be very significant e.g. > AU$400 M for a sugar mill capable of producing 350,000 t of sugar per year.

Providing market access in Asia for horticultural products improved gross margins though not as significantly as for industrial crops or broadacre crops. Although the estimated freight costs were reduced the additional costs associated with meeting export protocols (e.g. quarantine and inspection, fruit treatment) offset the freight benefits.

Depending on the size of the irrigation scheme and crops grown, regional gross product increased from around AU$50M to AU$1Bn (Table 7). The results expressed in Table 7 are on the basis of total value of production averaged over all years, discounted for water reliability using the reliability values in Table 2. Scenarios that used larger areas of horticulture or sandalwood generated the highest returns per ha (Ord, Mataranka) whilst those dominated by broadacre cropping produced gross returns of $4000 to $7000/ha. In the Ord and Flinders and Gilbert regions Scenario 2 produced very high tonnages of production but lower gross returns than Scenario 1. This was a result of Scenario 2 having large areas of sugarcane, which produced high tonnages of cane per ha but this raw cane had a relatively low value per tonne. There was some limited double cropping in these broadacre cropping scenarios e.g. cotton double cropped with lablab, guar or mungbeans in the Pilbara, and rice double cropped with chickpeas in the Flinders and Gilbert region.

Fig. 3 shows the financial outcome measured as annual debt per hectare over 10 years for a farm growing cotton in the Ord region, where the types of years experienced following investment and enterprise establishment occur in different sequences. The results show that for the medium-debt scenario ($12,000/ha), experiencing below median yield years at the start of the investment period led to a period of 5 years or more before capital debt declined. This contrasted with a sequence of above median yield years in the first half of the investment period where some of the capital debt was reduced quickly. Even though this scenario experienced the same 10 individual years as the scenario where below median yield years were earlier in the sequence, it always maintained an advantage. Experiencing two significant crop failures in the 10-year period resulted in debt increasing through time with little prospect for recovery.

4. Discussion

Policy initiatives to support intensive agricultural development in northern Australia have a long history (McKellar et al. 2015). Primarily they have been founded on a desire to create vibrant economies and communities in northern Australia but more recently emphasising the potential to provide agricultural commodities for a world in which food demand continues to rise, especially in Asian countries to the north of Australia. A general assumption underpinning these development initiatives is that irrigated agriculture will be profitable and will contribute positively to regional economies. The results from this study do indicate that expanding irrigated agricultural production in northern Australia has the potential to add considerable gross value to the

Table 6
Change in gross margin for a range of selected crops in response to altered location of processing facilities or market destination.

Crop	Location for market or processing-baseline	Gross margin ($/Ha)	Location for market or processing scenario	Gross margin ($/Ha)	Assumptions for supply chain scenarios
Broadacre					
Ord					
Maize	Perth	− 451	Indonesia	375	Wyndham to Surabaya ship
Mataranka					
Peanut	Kingaroy	− 101	Katherine	488	Shelling plant in Katherine
Flinders/Gilbert					
Sorghum	Emerald	25	Richmond	386	Sorghum used in on-farm and commercial feedlots
Pilbara					
Maize	Perth	551	Asia	254	Exported via Port Hedland to China
Horticulture					
Ord					
Rockmelon	Adelaide	6097	Singapore	6268	Regular Wyndham to Singapore ship, additional quarantine costs
Mataranka					
Watermelon	Adelaide	10,108	Singapore	12,528	Regular Darwin to Singapore ship, cycling of refrigerated containers, additional quarantine costs
Flinders/Gilbert					
Mango	Brisbane	6944	Cairns/Asia	8022	Road transport to Cairns and then export by ship to Asia – excludes additional costs of export protocol requirements
Industrial					
Ord					
Cotton	Dalby	− 1624	Kununurra	1238	Cotton gin in Kununurra
Mataranka					
Cotton	Emerald	− 467	Kununurra	1115	Cotton gin in Kununurra
Pilbara					
Cotton	Menindee	− 455	Pilbara	1349	Cotton gin in Kununurra

Table 7
Value of crop production for two scenarios (described in Table 3) at the scheme scale.

Region	Scenario 1	Scenario 2
Ord		
Total annual production (tonnes)	434,583	2,984,149
Total value of production ($M)	979	564
Value of production ($/ha)	19,580	11,280
Mataranka		
Total annual production (tonnes)	92,500	61,300
Total value of production ($M)	129	62
Value of production ($/ha)	51,600	24,800
Flinders Gilbert		
Total annual production (tonnes)	429,250	3,745,000
Total value of production ($M)	314	195
Value of production ($/ha)	6980	4333
Pilbara		
Total annual production (tonnes)	188,400	61,300
Total value of production ($M)	43	49
Value of production ($/ha)	5375	6125

regional economy. However, an earlier economic analysis of the Flinders and Gilbert region of northern Australia did raise the question of whether the long-term net welfare benefit to the region is positive when all the public and private costs of development are considered (Wittwer and Banerjee 2015).

At the enterprise scale, for significant private investment in agricultural development to occur there needs to be a business case that can demonstrate profitability and acceptable returns on investment in the absence of significant government support. This study has shown that growing crops profitably is a significant challenge when returns are weighed up against the high costs of production, marketing and transport associated with operating in more remote regions of northern Australia. In addition to variable costs, 'greenfields' agricultural developments will incur significant capital costs. Petheram et al. (2016) found that gross margins needed to be at least AU$3000–AU$4000/ha to generate positive net present values for the underlying capital investment when using on-farm water storages for irrigation developments with capital costs in the order of AU$10,000/ha. The present study found that none of the broadacre crops that were examined could generate gross margins of AU$3000/ha. High value horticultural crops or niche crops such as sandalwood can generate high gross and net returns but they generally carry greater risk because capital costs of development are higher and a number of years can elapse before there are any returns (fruit trees, sandalwood).

Options to address the challenge of generating high enough gross margins for viable production include increasing returns and/or reducing costs. All of the broadacre crops that were investigated produced estimated or simulated yields that are potentially commercially viable. Simulated yields were either similar to or somewhat less than observed yields (up to 20% lower) in commercial cropping areas in the subtropics of eastern Australia. While the tropical climate provides challenges for some crops during a hot, humid summer, especially in relation to pests, diseases and damage from high rainfall events, there are also opportunities to grow summer field crops during the mild tropical winters. Crop yields could also be improved by further development of better adapted varieties and innovative agronomic management practices (Chapman et al. 1996). The potential to grow crops in both the wet and dry seasons under irrigation has the potential to increase farm incomes through rotational cropping systems. One of the challenges in realizing such a potential is in being able to manage farm operations so that time of sowing and optimum crop windows can be matched with seasonal conditions, trafficability of soils etc. (Yeates et al. 1996).

While growing high value horticultural crops is one possible avenue for generating higher returns, highly volatile prices because of finely balanced supply and demand can pose significant risks for production in northern Australia where cost structures are high. The best opportunities for horticultural crops exist where the growing season in northern Australia affords a timing advantage compared with other production regions in Australia. Given slowly rising domestic demand in Australia (Moir 2016) finding new export markets is needed to support greatly increased horticultural production in northern Australia. A combination of challenges including long timeframes to negotiate

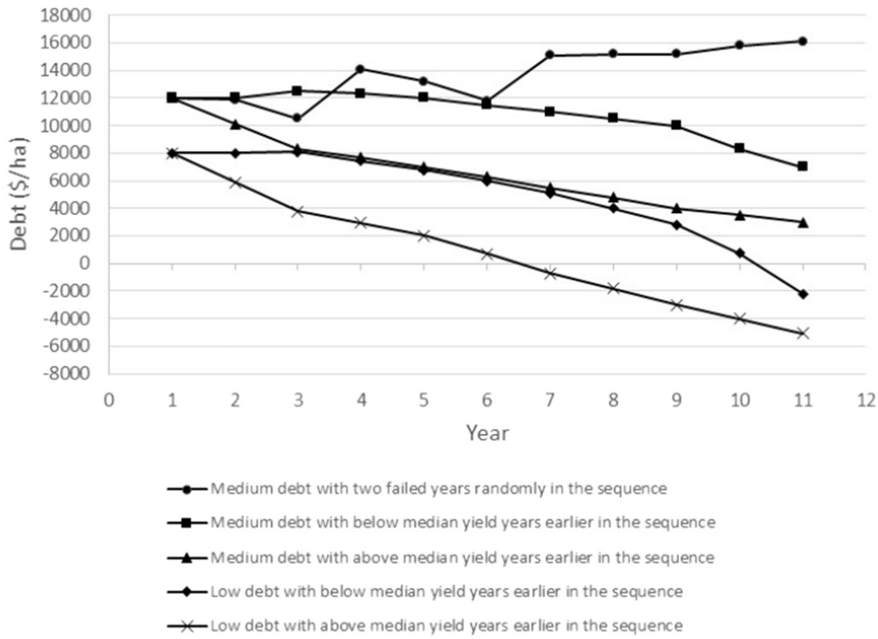

Fig. 3. Ord River case study — Influence of sequence of year types and starting debt level on the ability of cash flows to reduce debt over a 10-year investment period.

export protocols with target countries, high costs of production associated with labour and other input costs, import restrictions and the need for more direct routes for export produce will make successful export expansion a long term process that requires a fundamental change in existing supply chains. However, recent trade agreements with China, Japan and the Republic of Korea coupled with a lower Australian dollar suggests that export opportunities will improve significantly over the medium term (ABARES 2016).

Given the high contribution of transport to overall costs of production and marketing for most crops examined in this study, reducing this cost component is important to improving net returns. Nearly all crops produced in northern Australia are transported long distances by road to southern Australia. This is a particular impediment to the viability of high volume, low value broadacre crops.

There is almost no transport of horticultural produce by sea or air from northern Australian ports because of the concentration of freight routes to hubs and ports in major southern capital cities on the coast. It may be feasible to create refrigerated container capacity and shipping schedules that match seasonal production in northern Australia which would potentially reduce the costs of shipping from northern ports assuming that cost-effective quarantine and treatment protocols can be implemented. However, the current patterns of freight flows in and out of Australia and the associated cost structures are well entrenched and a change in the present routing of horticultural produce to southern Australia before it is exported north of Australia is not likely to occur in the foreseeable future, even under scenarios of greatly increased agricultural production in the north (Infrastructure Australia, 2015).

One option for removing the large transport cost for broadacre crops is some form of integration of production, processing or consumption activities at the regional scale i.e. crops grown in northern regions utilized within the region. Given that extensive livestock production, principally beef cattle, dominates land use in northern Australia, one possibility is to integrate crop-livestock systems at the regional scale. When used locally in beef fattening, both grains and forage hay crops may generate positive gross margins. Not only would this provide a market for such grains within the region but it would also offer scope for market diversity for the beef industry, which in those regions is strongly dependent on the live export trade (Greiner et al. 2014; Gleeson et al., 2012). Even if grains, pulses and high quality fodders are available locally for beef finishing systems, the economics of feedlot fattening has not been thoroughly evaluated. In addition to agronomic and economic considerations, for adoption of irrigation to occur by beef cattle producers there needs to be considerable capacity building at the level of communities of practice and individuals (McKellar et al. 2015).

Most industrial crops and some broadacre crops that were analysed in this study require local milling, ginning or shelling facilities in order to generate positive gross margins. Local processing facilities significantly reduce transport costs by reducing the quantity of non-saleable by-product requiring transport. For processing facilities to be viable there needs to be sufficient crop grown within a region and this brings into consideration aspects of regional development and coordination and economies of scale. However, infrastructure costs for processing facilities can be high e.g. > $400 M for a mill capable of producing 400,000 t of raw sugar per year, which is considered to be the minimum viable size by sugar milling companies. This can lead to an impasse in infrastructure investment where production and processing are not integrated within a single business. Farmers will not invest in the crop without a processing facility and businesses will not invest in the processing facility without some surety of supply. This issue highlights that innovation in 'greenfields' agricultural developments will require innovation not just at the farm scale but also in institutions and policy at regional and national scales (Schut et al. 2016).

There are other factors that will have an impact on the expansion of existing irrigated agriculture or the successful establishment of new ventures and schemes in northern Australia. While this study has demonstrated that potential crop yields are commercially viable it can take a number of years to learn the agronomic and management practices necessary to successfully grow these crops under local soil and climatic conditions. Quantitative approaches to factoring in learning into economic analysis of agricultural ventures are available (Marra et al. 2003) but many business plans ignore this cost and assume an overly optimistic timeframe for achieving stable returns. Extreme events associated with weather, pests or diseases also need to be considered and factored in to business plans. For example, recent incursions in northern Australia of rice blast and cucumber green mottle mosaic virus (Tesoriero et al. 2016) halted commercial production of rice and melons, respectively, in affected areas. The risk analysis undertaken highlighted that extreme events, either weather related or as a result of an unanticipated pest or disease outbreak, that resulted in crop failures in the early years of development and investment could test the viability of the enterprise.

While not explicitly addressed in this study, other factors of importance in new agricultural developments are environmental impacts and effects on other stakeholders and regional communities. This is a particular sensitivity in northern Australia where many of the ecosystems are relatively intact and indigenous people are living in proposed development areas. Stoeckl et al. (2013) demonstrated that generation of indigenous benefit required more than co-location of new agricultural developments with indigenous communities. Additionally, there are ecological risks to water dependent ecosystems resulting from irrigated agriculture. Minimising the offsite impacts of agriculture are particularly important where they impact on ecosystems of nationally and international significance, such as the Great Barrier Reef (Thorburn et al. 2013).

The preceding discussion has highlighted that many factors need to be considered when undertaking 'greenfields' agricultural developments in new environments. The complexity of the biophysical and socio-economic systems means that there will be many challenges that require addressing through careful planning, a long-term commitment and the right mix of policies, institutions, technologies, and human capacity. The clearest large-scale example of 'greenfields' development in a savanna environment akin to northern Australia is the Cerrado in Brazil, a region of around 2 million square kilometres. While the favourable climate in the Cerrado makes it amenable to dryland farming compared with the need for irrigated agriculture in northern Australia, the soils in the Cerrado are nutrient poor and acidic. Through technology advances in plant breeding, fertilisers, agronomy, and pest and disease management (Correa and Schmidt 2014), together with major road infrastructure improvements and other supporting policies, productivity in the Cerrado increased by 192% over two decades (Rada 2013). These large gains in productivity were mostly achieved by greatly increasing inputs rather than through resource efficiencies (Rada 2013) and have come at some significant environmental cost (Martinelli et al. 2010). This highlights the challenges facing large-scale agricultural development in harsh environments and the need to understand systems implications in terms of economic and social factors, environment, and policy support.

5. Conclusion

The analysis undertaken in this study, supported by lessons from past agricultural developments, suggest that successful agricultural development at scale requires all components of the system to be considered holistically. This would appear to be particularly important in the context of northern Australia because each component of the system – climate, soils, water, agronomy, pests and diseases, farm operations, management, planning, supply chains, infrastructure, labour, services, markets, ecosystem impacts and undesirable community impacts – can individually act as a significant constraint to profitable and sustainable enterprises. Managing the complexity of these component factors as well as scaling up at a considered pace and being prepared for considerable (5–15 year) lags before positive returns on investment are achieved are critical for successful long-term agricultural ventures in northern Australia.

Acknowledgements

The authors would like to acknowledge the financial support provided by the Office of Northern Australia, Commonwealth Government of Australia, to undertake the Food and Fibre Supply Chain Study, which provided the data and analysis underpinning this research paper.

References

ABARES, 2016. Agricultural Commodities: March Quarter 2016. CC BY 3.0.
Yeates, S.J., Abrecht, D.G., Price, T.P., Mollah, W.S., Hausler, P., 1996. Operational aspects of ley farming systems in the semi-arid tropics of northern Australia: a review. Aust. J. Exp. Agric. 36, 1025–1035.
Anon, 2014. White Paper on Developing Northern Australia. Available at: http://northernaustralia.dpmc.gov.au/.
Ash, A.J., 2014. Factors Driving the Viability of Major Cropping Investments in Northern Australia — A Historical Analysis. CSIRO, Australia.
ASRIS, 2014. ASRIS — Australian Soil Resource Information System. CSIRO Land and Water, Canberra Viewed February 2014. http://www.asris.csiro.au.
Infrastructure Australia, 2015. Northern Australia Audit: Infrastructure for a Developing North. Australian Government, Canberra.
Bartley, R., Thomas, M.F., Clifford, D., Phillip, S., Brough, D.H., Harms, D., Willis, R., Gregory, L., Glover, M., Moodie, K., Sugars, M., Eyre, L., Smith, D.J., Hicks, W., Petheram, C., 2013. Land suitability: technical methods. In: A Technical Report to the Australian Government for the Flinders and Gilbert Agricultural Resource Assessment (FGARA) Project. CSIRO, Australia.
Biggs, A.J.W., Philip, S.R., 1995. Soils of Cape York Peninsula. Queensland Department of Primary Industries, Mareeba.
Chapman, A.L., Sturtz, J.D., Cogle, A.L., Mollah, W.S., Bateman, R.J., 1996. Farming systems in the Australian semi-arid tropics — A recent history. Aust. J. Exp. Agric. 36, 915–928.
Christian, C.S., Stewart, G.A., 1953. General report on survey of Katherine-Darwin region, 1946. In: Land Research Series No. 1. CSIRO, Melbourne.
Cook, G., 2009. Historical perspectives on land use development in northern Australia: with emphasis on the Northern Territory. In: Stone, P. (Ed.), Northern Australian Land and Water Science Review 2009. Northern Australia Land and Water Taskforce and CSIRO, Canberra (Chapter 6).
Correa, P., Schmidt, C., 2014. Public Research Organizations and Agricultural Development in Brazil: How Did EMBRAPA Get It Right? Poverty Reduction and Economic Management (Prem) Network. 145. The World Bank. Junepp. 2014.
FAO, 2009. How to Feed the World in 2050. FAO, Rome.
Garside, A.L., Bell, M.J., 2011. Growth and yield responses to amendments to the sugarcane monoculture: effects of crop, pasture and bare fallow breaks and soil fumigation on plant and ratoon crops. Crop Pasture Sci. 62, 396–412.
Gleeson, T., Martin, P., Mifsud, C., 2012. Northern Australian beef industry: assessment of risks and opportunities. In: ABARES Report to Client Prepared for the Northern Australia Ministerial Forum, Canberra, (May 2012).
Wilson, P.L., Gregory, G., Watson, I., 2013. Land and soil resources. In: Grice, A.C., Watson, I., Stone, P. (Eds.), Mosaic Irrigation for the Northern Australian Beef Industry: An Assessment of Sustainability and Potential. CSIRO, Brisbane A report prepared for the Office of Northern Australia.
Greiner, R., Puig, J., Huchery, C., Collier, N., Garnett, S., 2014. Scenario modelling to support industry strategic planning and decision making. Environ. Model. Softw. 55, 120–131.
Higgins, A., McFallan, S., Laredo, L., Prestwidge, D., Stone, P., 2015. TRANSIT — a model for simulating infrastructure and policy interventions in agriculture logistics: application to the northern Australia beef industry computers and electronics in agriculture. Comput. Electron. Agric. 114, 32–42.
Jeffrey, S.J., Carter, J.O., Moodie, K.B., Beswick, A.R., 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environ. Model. Softw. 16, 309–330.
Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. Eur. J. Agron. 18, 267–288.
Malcolm, L.R., Makeham, J.P., Wright, V., 2005. The Farming Game: Agricultural Management and Marketing. Cambridge University Press, Melbourne.
Marra, M., Pannell, D.J., Ghadimb, A.A., 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? Agric. Syst. 75, 215–234.
Martinelli, L.A., Naylo, R., Vitousek, P.M., Moutinho, P., 2010. Agriculture in Brazil: impacts, costs, and opportunities for a sustainable future. Curr. Opin. Environ. Sustain. 2, 431–438.
McCown, R.L., 1996. Being realistic about no-tillage, legume ley farming for the Australian semi-arid tropics. Aust. J. Exp. Agric. 36, 1069–1080.
McKellar, L., Bark, R.H., Watson, I., 2015. Agricultural transition and land-use change: considerations in the development of irrigated enterprises in the rangelands of northern Australia. Rangeland J. 37, 445–457.
Moir, B., 2016. Horticulture: the road ahead. In: Australian Bureau of Agriculture and Resource Economics and Sciences, Outlook Conference, Canberra, 1–2 March, 2016.
Pearson, D., Gorman, J., 2010. Managing the landscapes of the Australian Northern Territory for sustainability: visions, issues and strategies for successful planning. Futures 42, 711–722.
Petheram, C., McMahon, T.A., Peel, M., 2008. Flow characteristics of rivers in northern Australia: implications for development. J. Hydrol. 357, 93–111.
Petheram, C., Watson, I., Stone, P. (Eds.), 2013. Agricultural Resource Assessment for the Flinders Catchment. A Report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, Part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.
Petheram, C., Watson, I., Stone, P. (Eds.), 2013. Agricultural Resource Assessment for the Gilbert Catchment. A Report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, Part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.

Petheram, C., Gallant, J., Wilson, P., Stone, P., Read, A., Eades, G., Tickell, S., Commander, P., Moon, A., McFarlane, D., Marvanek, S., 2014. Northern Rivers and Dams: A Preliminary Assessment of Surface Water Storage Potential for Northern Australia. CSIRO Land and Water Flagship Technical Report. CSIRO, Australia.
Petheram, C., McKellar, L., Holz, L., Poulton, P., Podger, S., Yeates, S., 2016. Evaluation of the economic feasibility of water harvesting for irrigation in a large semi-arid tropical catchment in northern Australia. Agric. Syst. 142, 84–98. http://dx.doi.org/10.1016/j.agsy.2015.11.007.
Rada, N., 2013. Assessing Brazil's Cerrado agricultural miracle. Food Policy 38, 146–155.
Reardon, R., Timmer, C., 2014. Five inter-linked transformations in the Asian agrifood economy: food security implications. Glob. Food Sec. 3, 108–117.
Regional Australia Institute, 2013. Rethinking the future of Northern Australia's regions. In: Regional Research Report — November 2013. Canberra, Regional Australia Institute.
Schoknecht, N.R., Grose, C.J., 1996. Soils of the Mantinea Loop Ord River Valley East Kimberley Western Australia. Natural Resources Assessment Group, Agriculture Western Australia, South Perth.
Schut, M., van Asten, P., Okafor, C., Hicintuka, C., Mapatano, S., Nabahungu, N.L., Kagabo, D., Muchunguzi, P., Njukwe, E., Dontsop-Nguezet, P.M., Sartas, M., Vanlauwe, B., 2016. Sustainable intensification of agricultural systems in the Central African Highlands: the need for institutional innovation. Agric. Syst. 145, 165–176. http://dx.doi.org/10.1016/j.agsy.2016.03.005.
Stoeckl, N., Jackson, S., Pantus, F., Finn, M., Kennard, M.J., Pusey, B.J., 2013. An integrated assessment of financial, hydrological, ecological and social impacts of 'development' on Indigenous and non-Indigenous people. Biol. Conserv. 159, 214–221.
Tesoriero, L.A., Chambers, G., Srivastava, M., Smith, S., Conde, B., Tran-Nguyen, L.T.T., 2016. First report of cucumber green mottle mosaic virus in Australia. Aust Plant Dis Notes 11, 1. http://dx.doi.org/10.1007/s13314-015-0186-x.
Thorburn, P.J., Wilkinson, S.N., Silburn, D.M., 2013. Water quality in agricultural lands draining to the Great Barrier Reef: a review of causes, management and priorities. Agric. Ecosyst. Environ. 180, 4–20.
Wittwer, G., Banerjee, O., 2015. Investing in irrigation development in North West Queensland, Australia. Aust. J. Agric. Resour. Econ. 59, 189–207.