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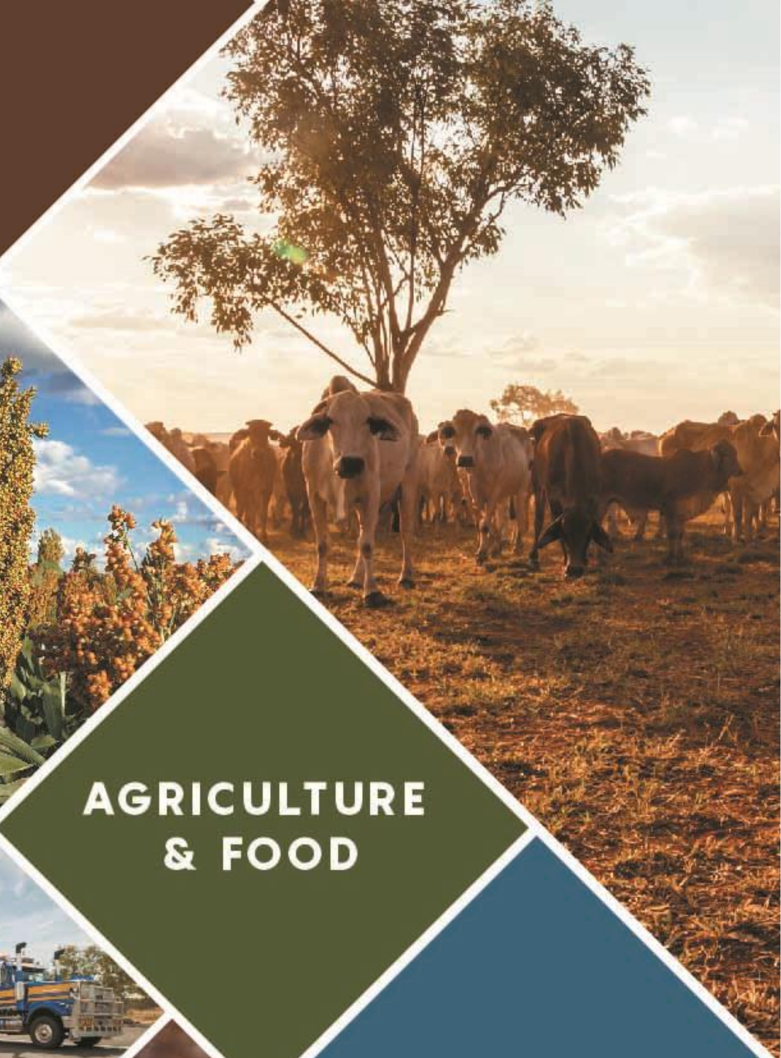

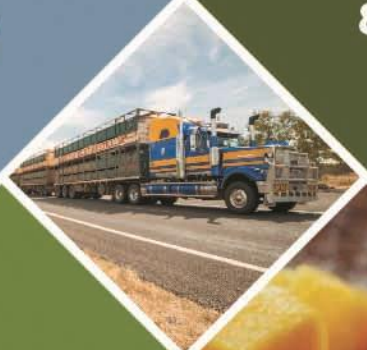

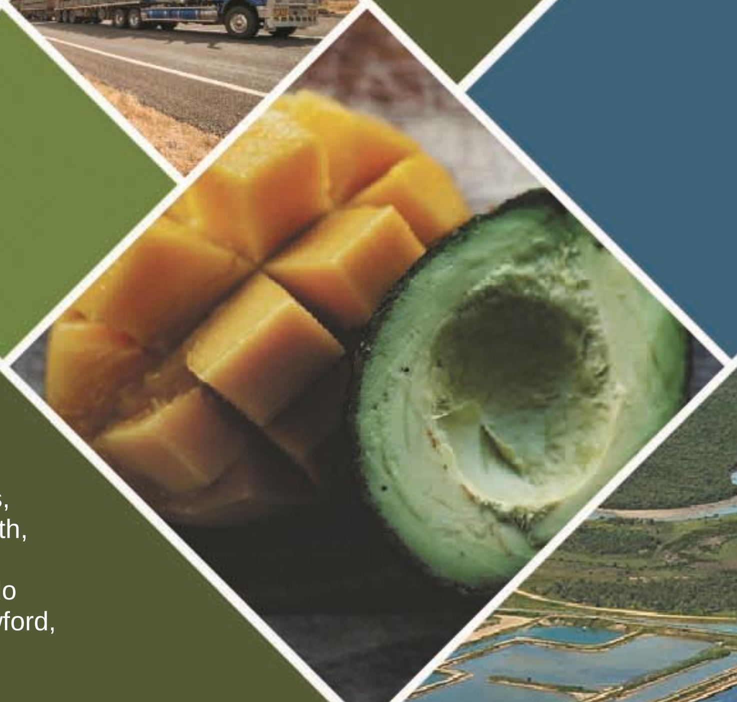

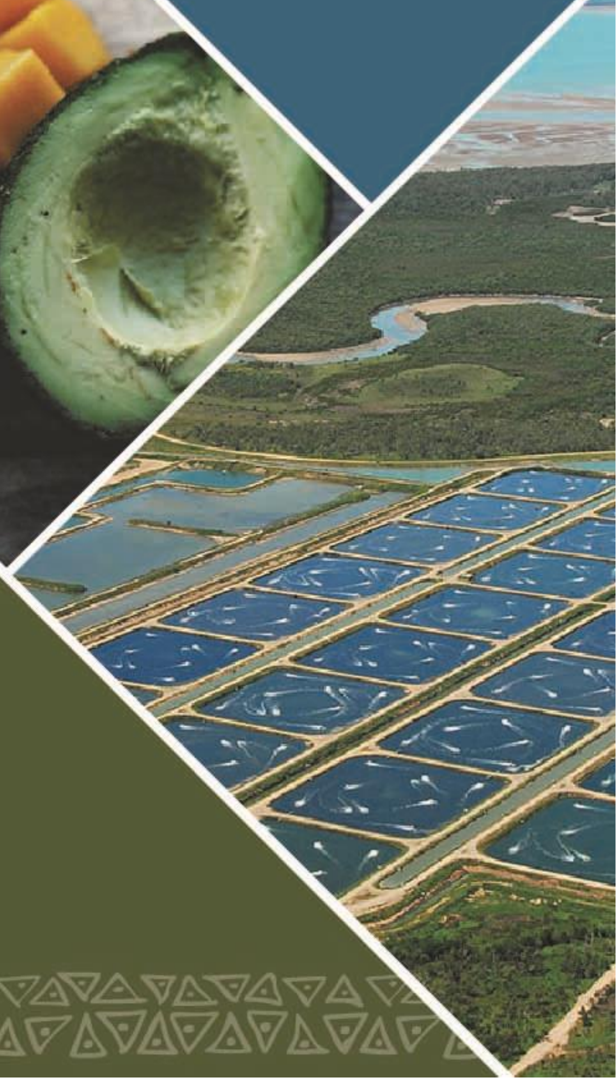

Project A.2.1819004: Potential for Broadacre Cropping in the NT

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Disclaimer

Peer Review Statement

The CRCNA recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.
The authors confirm that this document has been reviewed and approved by the program leader.

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AusIndustry
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NORTHERN TERRITORY GOVERNMENT

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Table of contents

List of Tables

List of Figures

List of Photos

Acronyms

NT	Northern Territory
NT	Northern Territory
NTG	Northern Territory Government
DDRF	Douglas Daly Research Farm
KRS	Katherine Research Station
DITT	Department of Industry, Trade and Tourism
CRCNA	Cooperative Research Centre for developing Northern Australia
GRDC	Grains Research and Development Cooperation
CRDC	Cotton Research and Development Cooperation
DITT	Department of Industry, Tourism and Trade
NTG-DITT	Northern Territory Government Department of Industry, Tourism and Trade
DEPWS	Department of Environment, Parks and Water Security
NTG-DEPWS	Northern Territory Government Department of Environment, Parks and Water Security
DAF	Department of Agriculture and Fisheries
USQ	University of Southern Queensland
CSIRO	Commonwealth Scientific and Industrial Research Organisation
NTFA	Northern Territory Farmers Association Incorporate
PPP	Project Participants' Panel
SAGI	Statistics for the Australian Grains Industry
APSIM	Agricultural Production Systems Simulator

Project Participants

Co-contributors

- Grains Research and Development Cooperation (GRDC)
- Cotton Research and Development Cooperation (CRDC)
- Department of Industry, Tourism and Trade (DITT) of the Northern Territory Government
- Department of Environment, Parks and Water Security (DEPWS) of the Northern Territory Government
- Department of Agriculture and Fisheries (DAF), Queensland Government
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- University of Southern Queensland (USQ)
- Northern Territory Farmers Association Incorporate (NT Farmers)

Participants

- Tipperary Station
- Ruby Downs
- Oolloo Farms
- Edith Springs Station
- Carbeen Park
- Glen Arden
- Cotton Seed Distributors Limited (CSD)

Executive Summary

Cooperative Research Centre for developing Northern Australia (CRCNA) commissioned the project “A.2.1819004: Potential for Broadacre Cropping in the NT” for assessment of the land, water and climate of the Northern Territory for commercial production of cotton and grain crops. Cotton Research and Development Cooperation (CRDC) and Grains Research and Development Cooperation (GRDC) co-contributed in project design and financial allocations. The project implementation was led by the Northern Territory Government’s Department of Industry Tourism and Trade, and project collaborators included the Northern Territory Farmers Association Inc (NT Farmers), Department of Environment, Parks and Water Security (DEPWS) of the Northern Territory Government, Department of Agriculture and Fisheries (DAF) of the Queensland Government, Commonwealth Scientific and Industrial Research Organisation (CSIRO), University of Southern Queensland (USQ), and commercial stakeholders of the Northern Territory’s plant-based industries.

Specifically, the project aimed to identify potential crops, the timing and length of the potential cropping windows, and the impacts of climate and edaphic conditions on yield and quality. Where accessible, any historical data of previous cropping trials conducted in the Northern Territory was acquired. Field trials were established at Northern Territory Government’s research farms and commercial properties. These data were used to determine the productivity of broadacre cropping systems by applying Agricultural Production Systems sIMulator (APSIM) - to investigate how a range of crop species will perform in terms of production and risk profile across the trial sites. Validation trials were conducted under rainfed and irrigated planting systems.

Validation trials included an intensive in-crop sampling and monitoring protocol to match simulated output to actual plant growth dynamics. This included soil sampling to at least 1.5 m with full soil water characteristics being determined. Above ground plant data collected in-crop included crop management records, full phenological monitoring, and at determined intervals leaf area, biomass, plant population and light interception, and crop yields.

The natural resource database determined the possibility of sowing crops during the breaks in the wet season - that allows the crops to best capture wet season rainfall and thus have sufficient soil moisture to carry a crop through to harvest. Soil type was found be a strong determinant of this strategy. The project findings suggest that the natural resource database to enable simulated productivity be measured on a regional scale to provide detailed indication of industry’s potential to expand into commercial broadacre farming.

The APSIM modelled output for cotton and peanut provided an initial indication of the potential and extent of possible broadacre agriculture across the Northern Territory. The APSIM analysis was also trialled by adapting proven online tools (CropARM) as a resource to allow stakeholders to assess cropping options in the Northern Territory. Since the crop simulations allow for virtual cropping over numerous years the impact of the highly variable Northern Territory weather on year to year viability of cropping can be assessed. This will allow for economic analysis to be completed to understand the financial implications for investing in this form of agriculture. This information will help to direct future agricultural RD&E in the Territory. Further this will assist planners to understand the infrastructure required to support this potential cropping industry. To this end, the virtual cropping has highlighted some issues and knowledge gaps that will require further research to answer,

hence overcoming a shortage of learned experience regarding broadacre cropping in the Northern Territory.

Finally, in addition to the field trials and modelling, the project addressed the low local knowledge of farming by providing advice and back-up for multiple on-farm commercial trial plantings of both cotton and grains crops. These trials acted as assessment sites for crop simulations, learning sites for the farms concerned and as demonstration sites to extend cropping practice to other local producers.

1. Introduction

1.1 Overview

The Northern Territory (NT) farmers maintain an expectation that the suitable areas of the semi-arid tropics from rangeland cattle grazing be transformed to dry land cropping. Previously, the costs, risks and returns of broadacre cropping never matched the expectations and eventually each attempt to develop commercial broadacre cropping was withered. Introduction of new genetics, especially in cotton, provides the incentive to revisit these crops and the growing potential of export markets are tempting the stakeholders to invest in research and development to determine possibilities of the broadacre cropping in the NT. Alongside cotton, grain crops are considered effective rotation for sustainable farming.

Historically, extensive agronomic research has been conducted into the crop species to grow in the NT but the efforts to pull this into a complete farming system have been lacking. Also, the knowledge from past studies to investigate the potential for broadacre cropping across the NT and the insights from the simulations to on-farm trials and extension of broadacre farming methods to NT producers needs to be collated and applied for informed further research and development. The natural resource database determined the possibility of sowing crops during the breaks in the wet season. Sowing crops at this time allows these crops to best capture wet season rainfall and thus have sufficient soil moisture to carry a crop through to harvest. Soil type has also been identified as a strong determinant of this strategy. This information can be utilised to guide the development of farm management strategies. The productivity of these management strategies can be virtually tested by simulation. Further the natural resource database enabled simulated productivity can be measured on a regional scale to provide an indication of industry potential.

What exactly is required to develop a complete farming system for broadacre cropping in the NT has remained a researchable question. This is required for establishing a sustainable broadacre cropping industry for the NT, for validation of specific crop simulation packages, and for application of the validated model to the commercial demonstration trial sites. Better understanding of the crop establishment and performance indicators can guide future broadacre research and development investment in the Territory.

1.2 Scope of the Project

Addressing the aforementioned research gaps, this project was funded by CRCNA to collate the historical broadacre cropping experience, natural resource information and an understanding of market opportunities to support the development of viable broadacre cropping systems in the NT. This was achieved by project partners bringing unique expertise to develop crop management strategies that helped to de-risk broadacre agriculture in the Territory. Core project activities focused on the following:-

- Simulation of rainfed cotton yield potential
- Monitoring of commercial cotton fields 2019-20
- Cotton row spacing comparisons - 2021 and 2022

- Maximising cotton seedling establishment
- Implementing Northern Territory locations into the CropARM decision support tool
- Performance and applications of the APSIM model for broadacre cropping of peanut and exploring the potential of chickpea
- Capacity building

Initially the pre-existing natural resource database was used to determine cropping windows and opportunities to sow crops during the tropical wet season and understand weather factors in other regions of the NT. Further, this was used to assess the risks associated with rain-fed dryland cropping in these conditions. Research validated APSIM for the semi-arid tropical environment of the NT to strengthen the predictive ability of APSIM to simulate cropping in new locations across tropical northern Australia. Validation crop species were limited to cotton and peanut in this project due to the short time frames. Cotton and peanuts were selected due to their high value of the produced commodity and because they have shown that both crops can be grown in the regions of interest. Where possible, historical data was used to gain an understanding of simulation outcomes from other crop types.

A component of the extension plan for this project introduced producers to simple methods to establish precision and robustness for on-farm crop trials. On-farm demonstration crop plots were planted on commercial properties for 1) additional testing of the crop simulation models, and 2) experience for the producer and extension site for promoting agricultural method to local producers. The project team worked with collaborating farmers to ensure that the on-farm demonstration plots were achieving their goal while not impeding commercial farm operations.

1.3 General Methodology

This section provides an overview of the methodology at project level - across all the core activities. Specific methodology of each of the core project activities are provided in respective sections (2-8) of this report.

Project Participants' Panel (PPP)

A Project Participants' Panel (PPP) comprising of key project participants and invited industry representatives guided crop management scenarios and interpretation of simulation and trial results, by applying local knowledge 'filters' to ensure the commercial applicability of modelled scenarios. Specifically, the PPP provided oversight and review for the project activities including potential cropping windows from the natural resource database for simulation testing, machinery 'workability' rules to apply to soils when considering cropping windows, preferred soil types to use for cropping simulations, and refine the crop management files with guidance from researchers and results from simulations.

Natural resource data

The natural resource database provided baseline data for crop simulation analysis, allowing for consideration of potential cropping windows and risk analysis for cropping operations at specific times through the year. Sources of the data included:-

a. Historical databases of soils characterisation across the NT is held by DEPWS to understand the mosaic and extent of soils across the region and gather enough data to enable soil files to be developed for use with crop simulation packages to simulate crops across this mosaic of soils.

b. Standard BOM weather station data were acquired. Weather at intermediate sites was determined from interpolated data. It is often found that actual weather extremes are more important than generalized weather data generated from interpolated sources.

Crop management scenarios

Following a review of past and current cropping strategies, the PPP was presented with possible crop management strategies that can be simulated. PPP considered the commercial practicality of these management strategies and provided guidance to the modelling teams of a suite of crop management strategies to simulate. The range of potential management strategies that the PPP set to be modelled within the time and budget constraints of the project were guided by the modelling teams. The management scenarios selected form one input for the CropARM on-line tool.

Crop demonstration plots on commercial farms

Producer demonstration sites were established on farmer's commercial properties. Key crops included cotton and peanuts, though other rotation crops, e.g., sorghum and chickpea were grown. Where these additional crops were grown their management and growth were recorded but they were not the key focus of this short-term project. All sites were visited by project research staff prior to commencement to check on trial site selection, develop a trial design and collect initial soil samples. All on-farm trials followed GRDC Statistics for the Australian Grains Industry (SAGI) guidelines for plot establishment and data collection. These protocols were vetted by project team and GRDC biometric staff for statistical rigour. Data collected from all sites included site information (site history and crop management details, soils, historical weather, and irrigation water quality), initial site conditions for soil nutrients and soil moisture, final yield, and final soil moisture content using methods as per Pembleton et.al., 2013. Detailed sampling protocols and recording sheets were developed by researchers and provided to producers undertaking these on farm trials.

PPP and researchers, while ensuring scientific rigour was applied, consulted commercial agronomic advisors to ensure commercial standards were followed, with regard to fertiliser requirement, timing and placement; sowing time, seed placement, and plant populations; weed, pest, and disease management; in-crop management; harvest preparation, timing, and method; and post-harvest grain handling. Dryland demonstration sites were planted in wet seasons 2019/2020 and 2020/2021, while irrigated sites were planted according to the best agronomic advice for those crops. It is recognized that currently there is a lack of farming equipment in the NT, especially for critical operations such as planting the crop. This project proposed to use a precision planter, acquired and coordinated by the NTFA, which was transported to various project collaborating farms (with some project funding helping to subsidize this transport). Target sowing dates were confirmed by the PPP following agronomic advice from crop experts and crop model and included after consideration of the compiled weather data in the natural resource database.

Communication and Extension plans

Communication and Extension plans were developed within the first three months of the project. These plans aimed to both aid uptake and development of broadacre cropping in the NT by local and interstate producers, and educate the general NT community what a broadacre cropping industry will mean for the NT. There is an undercurrent of discontent in the NT community with a cotton industry and irrigated agriculture in general. These communications aim to take these concerns into account and noting that it will not impact the community's trust in agriculture. Extension and education of local and interstate farmers looked at the unique challenges of cropping in the semi-arid tropics to understand and develop methods to embrace these environmental differences.

2. Simulation of Rainfed Cotton Yield Potential

2.1 Summary

Northern Territory has potential regions including Daly Basin, Larrimah and Wildman River, Keep River, Victoria River District plains and Roper River catchment that could support rainfed cotton production. However, there is limited information to guide the farmers to making on-farm decision about resource management targeting the potential lint yield across several soil types and climate in these potential cotton growing regions. The Agricultural Production Systems Simulator (APSIM) has been used in a broad range of applications to simulates biophysical process in farming systems like supporting on-farm decision making, farming systems design, and guide to researchers among others. In this research, simulation modelling with APSIM-OZCOT was used to evaluate the suitability of the above prospective cotton production regions. This study showed that the planting window that best balances achieved yields and planting opportunities is between 15-Dec and 15-Jan. Targeting soils with a larger PAWC (Oolloo, Blain and Heaton) in the higher rainfall regions (Daly Basin and Marrakai) showed the greatest potential for rainfed cotton production in the Northern Territory. Although the simulated yields on Oolloo soils were high based on the limited commercial experience. At the same time, unreasonably low frequency of planting on clay soils due to poor trafficability was also simulated. And lack of locally validated planting rules explained this as timely planting was achieved at the Ord River on heavy clays during the wet months (Late January to early March) for several seasons. Nevertheless, simulations for rain grown cotton south of Larrimah – i.e. Northern Barkly indicated unreliable cotton production. Nitrogen nutrient uptake in the Northern Territory soils was not validated against APSIM-OZCOT model. However, this is required for development of management strategies that best suit the different soil types used in this analysis.

2.2 Background

There are several regions in the NT that could potentially support rainfed and to an extent irrigated cotton production. These include those in the Daly Basin as well as potential new precincts in the Larrimah and Wildman River areas and the Keep River plains. Land resource assessments have also identified land in the Victoria River District (West Baines) and parts of the Roper River catchment as suitable for rainfed cotton as shown in figure 2.1 (NTG, 2021).

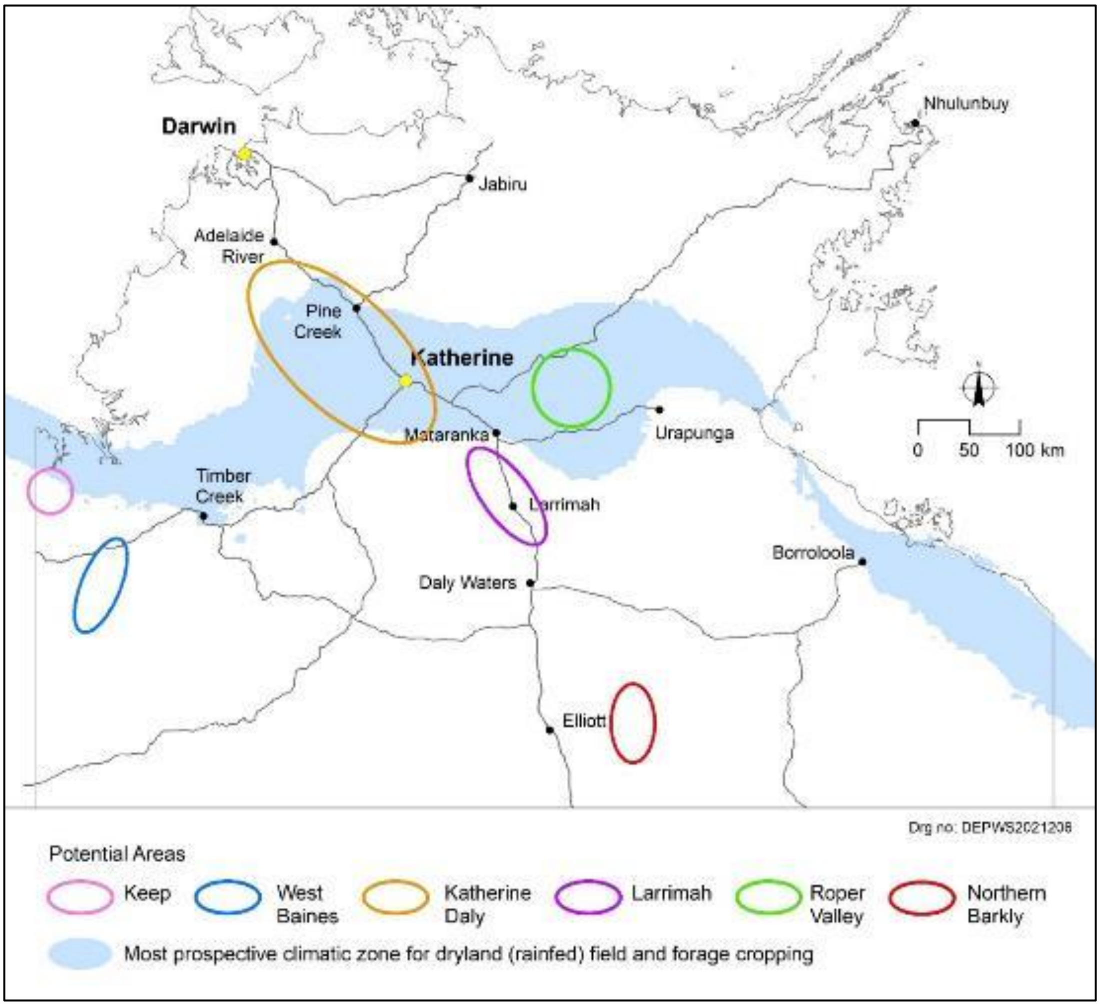

Fig. 2. 1 Most prospective areas for growing rainfed field and forage crops in the Northern Territory (NTG, 2021)

Targeting these potential cotton growing sites, we applied the cotton simulation model APSIM-OZCOT to evaluate the potential lint yield across several soil types and climate regions in the Northern Territory.

APSIM is a modular modelling framework that simulates biophysical process in farming systems. APSIM has been used in a broad range of applications, including support for on-farm decision making, farming systems design for production or resource management objectives, assessment of the value of seasonal climate forecasting, analysis of supply chain issues in agribusiness activities, development of waste management guidelines, risk assessment for government policy making and as a guide to research and education activity (Keating et al., 2003).

APSIM is linked to OZCOT, permitting the simulation of cotton production system scenarios on a wide range of soil types, climate, and management options. In this study, we used APSIM-OZCOT to understand the variability in production between seasons, which can greatly contribute to the strategic development of the cotton industry in Northern Australia.

2.3 Methodology

2.3.1 Climate regions

Prior to commercial industry development, potential growing areas for rainfed cotton in the NT were identified in two studies (NTG, 2021; Yeates, 2001). These broadly fall into two regions: 1) areas to the north and south of Katherine (Marrakai to Daly Waters), and 2) areas to the east and west of Katherine (West Baines to the Roper Catchment). In general, rainfall is greatest in the north, and gradually decreases when moving south, while the frequency of temperatures potentially detrimental to cotton growth (sub & supra) and development increases (Appendix 2B1 & 2B2). There is less variability in rainfall and temperature from west to east. Climate summaries for rainfall, evaporation and average temperature for several potential sites in the NT are shown in Figure 2.2 & 2.3. Summaries for radiation and max/min temperatures are shown in Appendix 2A & 2B.

2.3.2 Soil type

Soil sections need to be reviewed and restructured.Rainfed cotton requires adequate soil moisture at the start of the growing season (mid-Dec to mid-Jan in the NT), to reliably establish a healthy uniform stand, and after cut-out (last effective flower) in April-May, where sufficient soil moisture is needed to grow and finish bolls. Rainfed cotton is thus reliant on in-crop precipitation with minimal reliance on stored soil water as most soils in the NT are well-drained with low moisture holding capacity. By the end of the dry season (Oct–Nov) the soil has almost no plant available moisture left (Yeates and Poulton, 2019).

The most suitable soils across study sites in the NT are characterised as Red Kandosols, and are broadly distinguished by texture. These are Blain (sandy Red Earths), Oolloo (loamy Red Earths), Tippera (clayey Red Earths) and Heaton (sandy-loam Red Earths) soils (Edmeades, 2011). Red Kandosols are strongly weathered earths, and are usually well drained with low fertility.

Wildman soils, commonly known as grey or black cracking clays (Vertosols), are found in the floodplains at a number of potential cotton-growing sites but would require careful management for cotton cultivation since these soils are poorly to very poorly drained and waterlogged or inundated for several months of the year. In addition, soils with properties similar to Cununurra clay are found in Baines and the Roper catchment.

A number of soils have satisfactory characterisation for APSIM, including the Blain, Oolloo, Tippera, Wildman, and Cununurra clay soil group. Heaton soil group, was adapted from a generic Red Kandosol for the purpose of this study, using key parameters found in technical reports (Hignett, 2012; Mangion and Parkinson, 2012). Pedotransfer functions were used to predict Drained Upper Limit (DUL) and Lower Limit (LL15) (Palmer et al., 2017), and parameters for Saturation (SAT), Air Dry (AD) and Crop Lower Limit (CLL) were estimated using the ApSoil protocol (Dalgleish et al., 2016). The soil water characteristics for all soil types are shown in figure 2.4.

The Blain soil has a Plant Available Water Capacity (PAWC), or ‘bucket size’ of ~140 mm , Oolloo ~130 mm, Tippera ~80 mm, Heaton ~130 mm, Wildman ~130 mm and Cununurra Clay ~185 mm.

Critical to rainfed cotton is in-crop rainfall as well as stored soil moisture during the growing phase. Predictions and observations of soil water content at different soil depths are shown in appendix 2C. The graphs show that APSIM-OZCOT is adequate in simulating cotton water use for the rooting depth of the crop from sowing to maturity (60% open boll) on Oolloo soils. Initial nitrogen settings for each soil type are given in table 2.1 where data was taken from field recordings.

2.3.3 APSIM-OZCOT settings

Previous studies have suggested the most suitable planting window for rainfed cotton in the NT is from mid-December to mid-January (Yeates, 2001). Planting within this window has a greater likelihood to provide adequate soil moisture up to maturity and a lower risk of fibre discoloration and boll rots.

Sowing criteria were set between 15-Dec and 15-Jan, after a total of 30 mm of rain within 3 days and at least 20 mm of soil water. Cotton was sown at 30 mm depth, 7 plants/m row, and 1 m row width. To account for establishment failure caused by high soil temperature, a maximum soil temperature threshold was set at 40 °C. For clay soils (Wildman, Cununurra clay), a ‘too wet’ rule was added, where sowing commenced when soil water ≥ DUL in the top 2 soil layers (~40 cm) and the cumulative net potential evaporation was greater than 65 mm.

In the drier growing areas of the NT (south of Katherine), planting is often delayed due to the lack of mulch, and the likelihood of replanting is much higher if mulch is insufficient. A sequential cropping simulation was therefore set up where the mulch cover (sorghum) is grown from early season rainfall. The cotton sowing rule is only initiated when a mulch cover of 2 t/ha is achieved, and all other planting conditions are met.

2.3.4 Cultivar

For this study, the cultivar Sicot 748B3F was selected. Sicot 748B3F is a vigorous, full season variety, and performs well in dryland environments where full seasonal water cannot be guaranteed (CRDC and CottonInfo, 2021). APSIM-OZCOT cultivar settings for Sicot 748B3F have previously been calibrated, and are shown in table 2.2.

Table 2. 1 Sicot 748B3F cultivar settings in APSIM-OZCOT

Parameter	Description	Unit	Value
Percent_l	Percent lint	%	40
sqcon	Squaring constant	sites/degree day	0.014
DDISQ	Thermal time between seedling emergence and first square appearance	Degree days	540
dlds_max	The square root of leaf area increase per site	$\sqrt{(m^2/m^2/site)}$	0.17

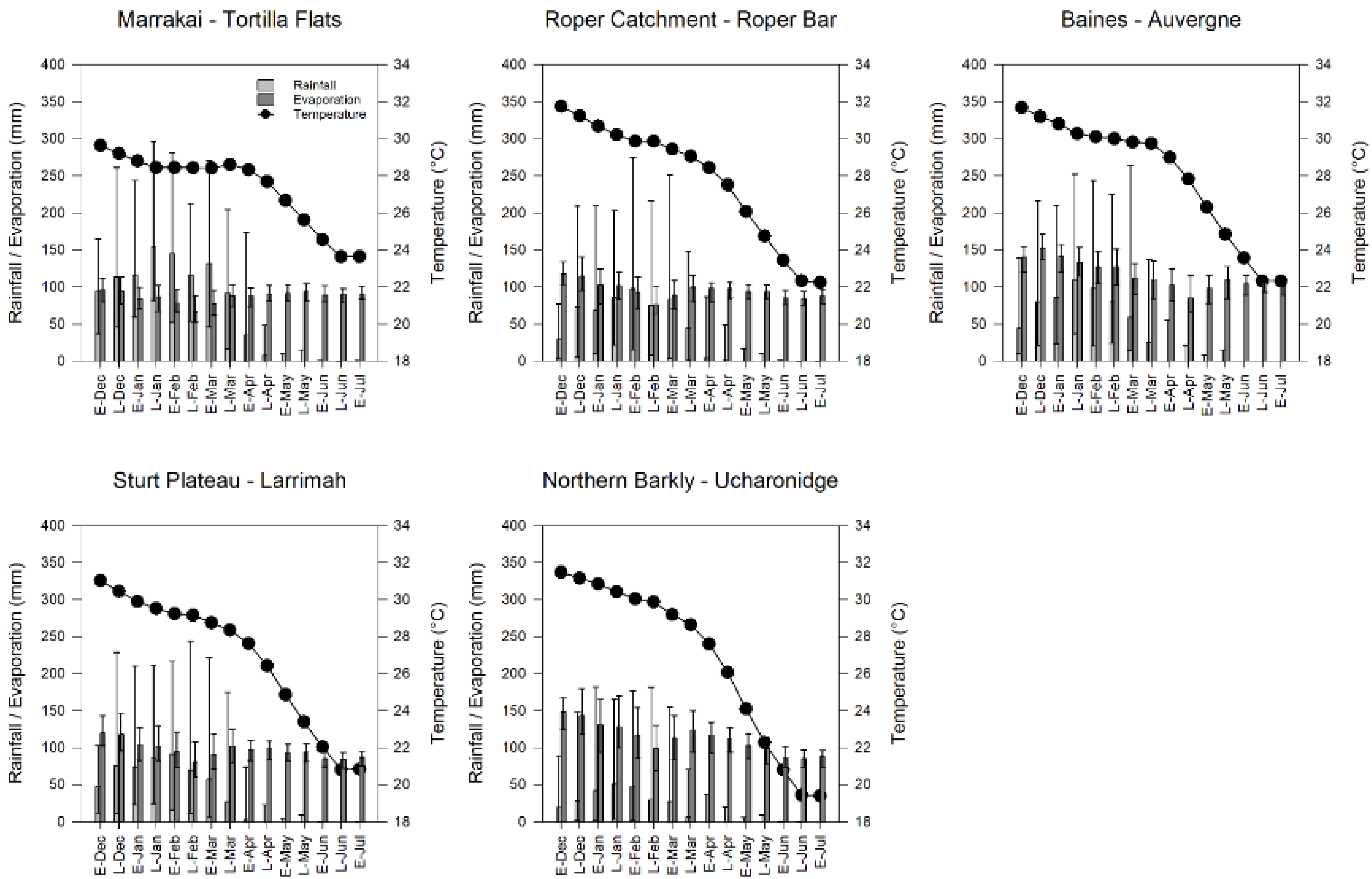

Fig. 2. 2 Half-monthly rainfall, evaporation and temperature for several potential cotton growing sites in the Northern Territory. Column bars show the median (50% of seasons) and error bars 10 to 90% of seasons (1957–2021). Temperature is plotted as the half-mon

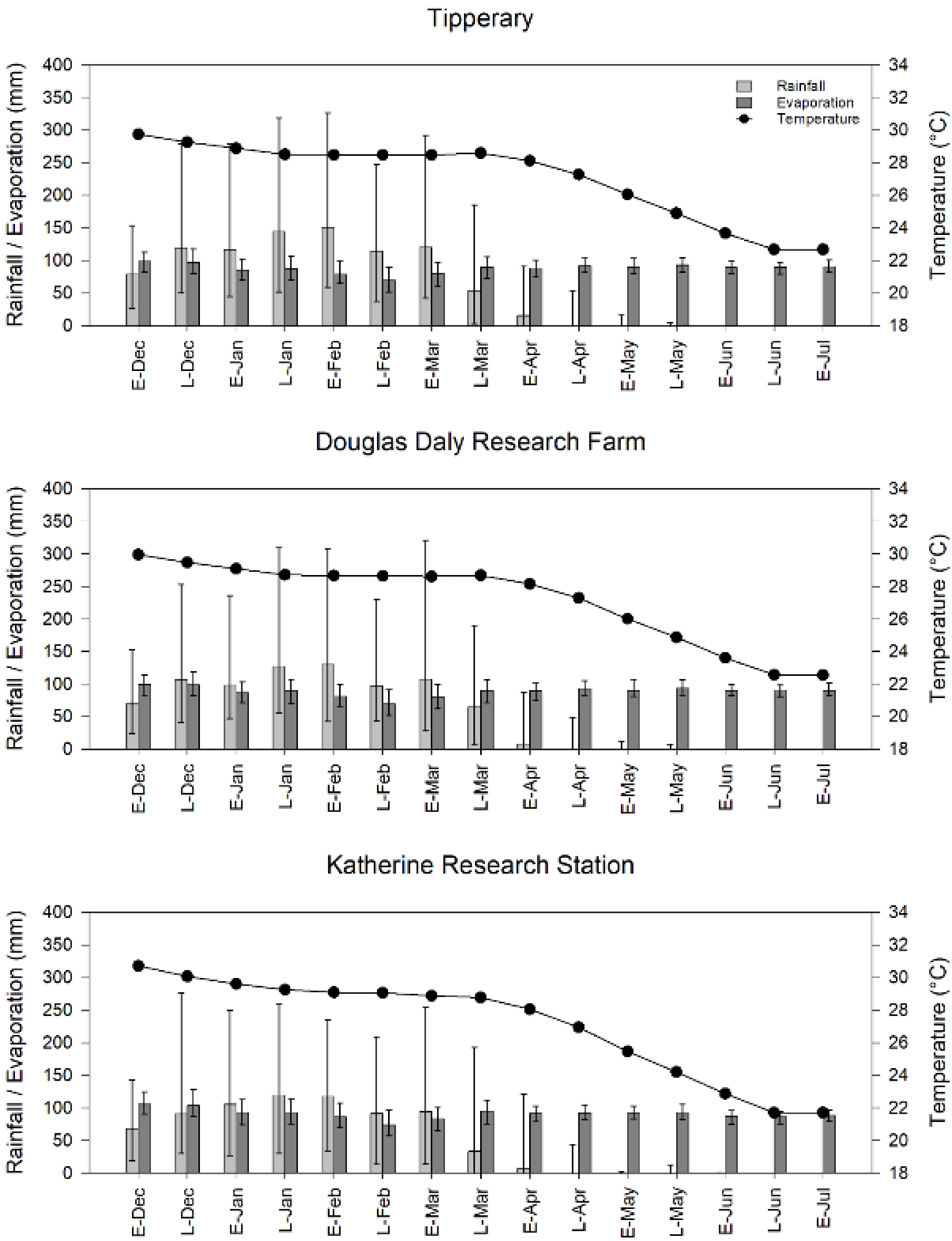

Fig. 2. 3 Half-monthly rainfall, evaporation and temperature for several potential cotton growing sites in the Daly Basin, Northern Territory. Column bars show the median (50% of seasons) and error bars 10 to 90% of seasons (1957–2021). Temperature is plotted as the half-monthly mean.

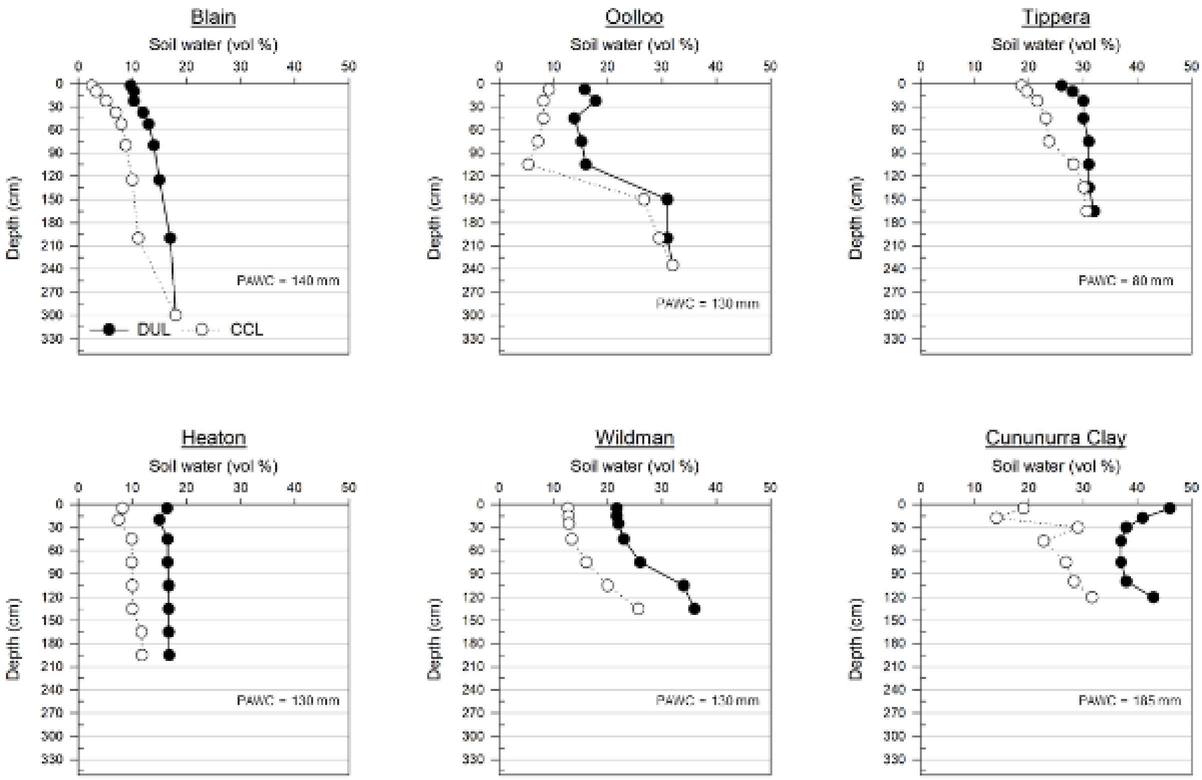

Fig. 2. 4 Typical Plant Available Water Capacity (PAWC) profiles for a cotton crop on soils found in potential cotton growing regions in the Northern Territory.

Solid circles show the Drained Upper Limit (DUL) and open circles the Crop Lower Limit (CLL) in vol. %.

Table 2. 2 Soil NO3- and NH4+ to 150 cm depth at planting for each soil type

Soil type	NO_3^- (ppm)	NH_4^+ (ppm)
Blain	10.9	0.7
Oolloo	5.7	4.4
Tippera	11.0	5.0
Heaton	12.5	0.6
Wildman	8.0	1.0
Cununurra clay	30.0	5.1

2.3.5 Nitrogen

Nitrogen response has not yet been validated for soils in the NT. Targeting a dryland yield of about 5 bales/ha, nitrogen fertilizer was applied at 100 kg N/ha, split 50:50 between planting and 30 days after sowing (CRDC and CottonInfo, 2018).

2.3.6 Surface organic matter

It is assumed that most sites have little soil cover or standing biomass at the end of the dry season. All simulations were therefore planted into a generic pasture, starting with a sorghum cover crop, with an initial surface residue of 1000 kg/ha and a carbon to nitrogen (C:N) ratio of 35.

2.3.7 Simulations

For this study, we ran crop model simulations for Tortilla Flats (Marrakai), Douglas Daly, Tipperary, Katherine (Daly Basin), Roper Bar (Roper Catchment), Auvergne (Baines), Larrimah (Sturt Plateau) and Ucharonidge (Northern Barkly) (Figure 2.5).

Fig. 2. 5 Location of study sites used for the APSIM-OZCOT crop model simulations.

In total 21 simulations were performed with APSIM-OZCOT, for each soil type identified at each location (Table 2.3). Climate files for each site were downloaded from the SILO database of Australian climate data (SILO | LongPaddock | Queensland Government) for the period 1957–2021. Management settings were similar for all simulations apart from a 'too wet' planting rule for clay soils.

Table 2. 3 Simulation combinations for location x soil type

Region	Location	Soil type					
		Blain	Oolloo	Tippera	Heaton	Wildman	Cununurra clay
Marrakai	Tortilla Flats				✓		
Daly Basin	Tipperary	✓	✓	✓			
	Douglas Daly Research Farm	✓	✓	✓			
	Katherine Research Station	✓		✓			
Roper Catchment	Roper Bar Store	✓		✓		✓	✓
Baines	Auvergne	✓		✓		✓	✓
Sturt Plateau	Larrimah	✓	✓	✓			
Northern Barkly	Ucharonidge					✓	

The number of planting days that occur within a planting window is key to the suitability of potential growing regions as it will determine whether sufficient hectares can be planted on time. The consequences of planting a week later or earlier than the planting window (15-Dec to 15-Jan) is also important as it will test the impact of changes in mulch cover and plant available soil water.
Next to the default simulations, the following scenarios were therefore explored:

1. Sowing date: early (1–15 Dec) and late (15-Jan to 1 Feb).
2. Increase and decrease in PAWC.

2.4 Results

2.4.1 Climate and soil effects on achievable cotton yields

Results of the yield simulations reflect the soil characteristics plant available water and rainfall infiltration rate, as well as the growing season rainfall received in each region (Figure 2.6).

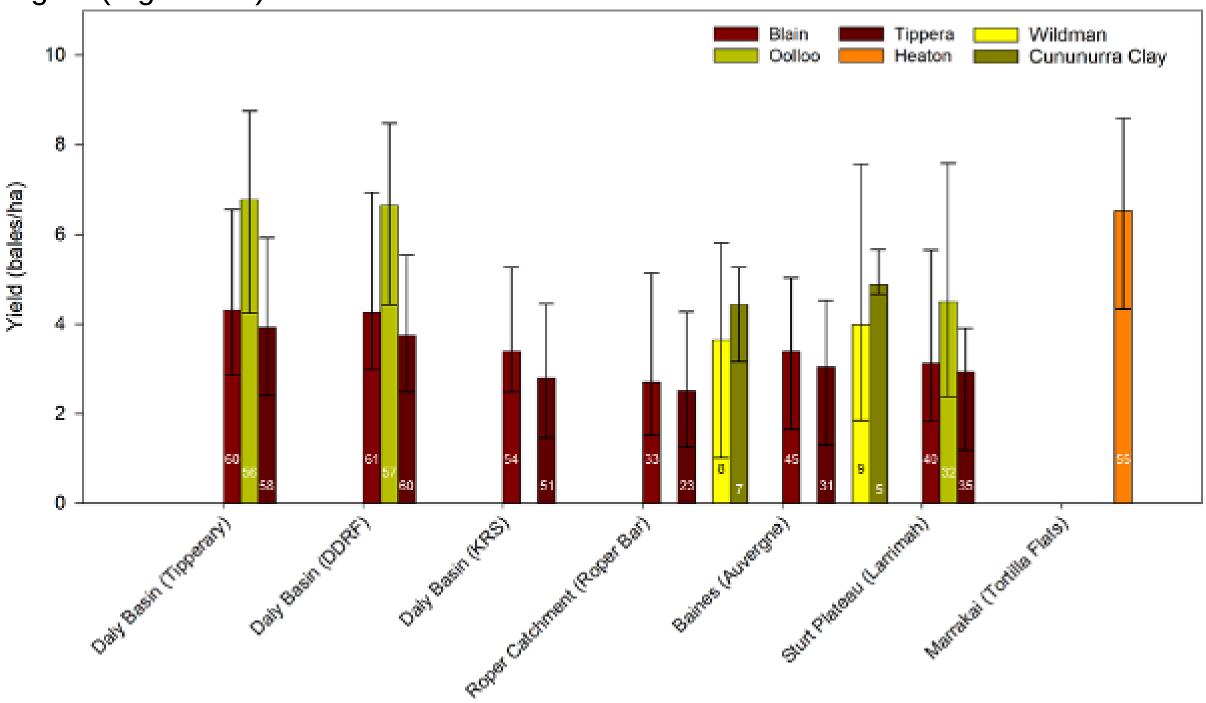

Fig. 2. 6 Simulated rainfed cotton yields for six soil types found in potential growing areas in the Northern Territory.

Column bars show the median (50% of seasons) and error bars 10 to 90% of seasons (1957–2021). The number of seasons that were planted (out of 65) are shown in the bars. Simulated yields are for a crop planted on the first day within the sowing window when planting was possible.

2.4.2 Planting window and number of planting days

Sites in Marrakai and the Daly Basin (Tipperary, Douglas Daly) receive greater amounts of rainfall over the cropping season (15-December to 15 April, Figure 2.7) and give larger yields on soils that hold more moisture (Figure 2.6).
Yields were larger on Oolloo soils compared with Blain soils due to a larger uptake of nitrogen (N) in most seasons. Clay soils were not suitable for rainfed cotton as they were often too wet to plant in most seasons. Results presented here do not account for the shrink-swell capacity of the clay soils, or the management thereof. Neither does

APSIM-OZCOT account for yield-reducing effects of pests, diseases and weeds, poor crop establishment, and nutrient deficiencies other than nitrogen.

In most cases, planting from 1–15 Dec produced the largest yields (Figure 2.8), but also corresponded to far fewer planting opportunities, most of which have a window of less than 5 days (Figure 2.9). A late planting (15-Dec to 1-Feb) resulted in more planting opportunities because more time was allowed to grow sufficient mulch cover – particularly in the southern (dryer) regions. However, yields were lower, simply because the crops ran out of water (Figure 2.8). Clay soils (Wildman, Cununurra clay) in the Roper, Baines and Northern Barkly offered very few planting opportunities (Figure 2.9). In most cases the soils were too wet to plant.

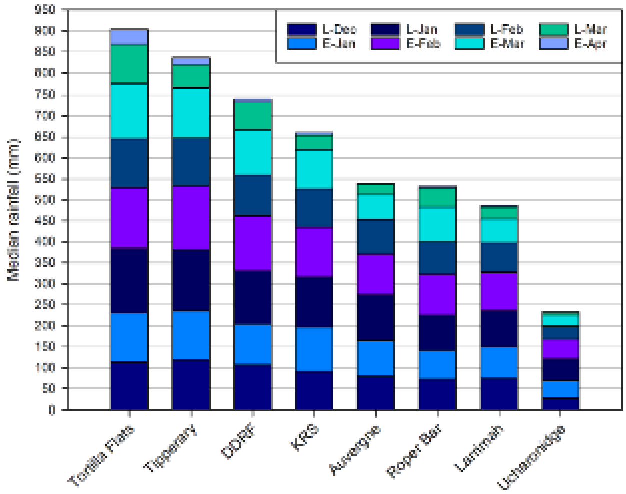

Fig. 2. 7 Cumulative median in-crop rainfall (15 Dec–15 Apr) for potential cotton growing sites in the Northern Territory

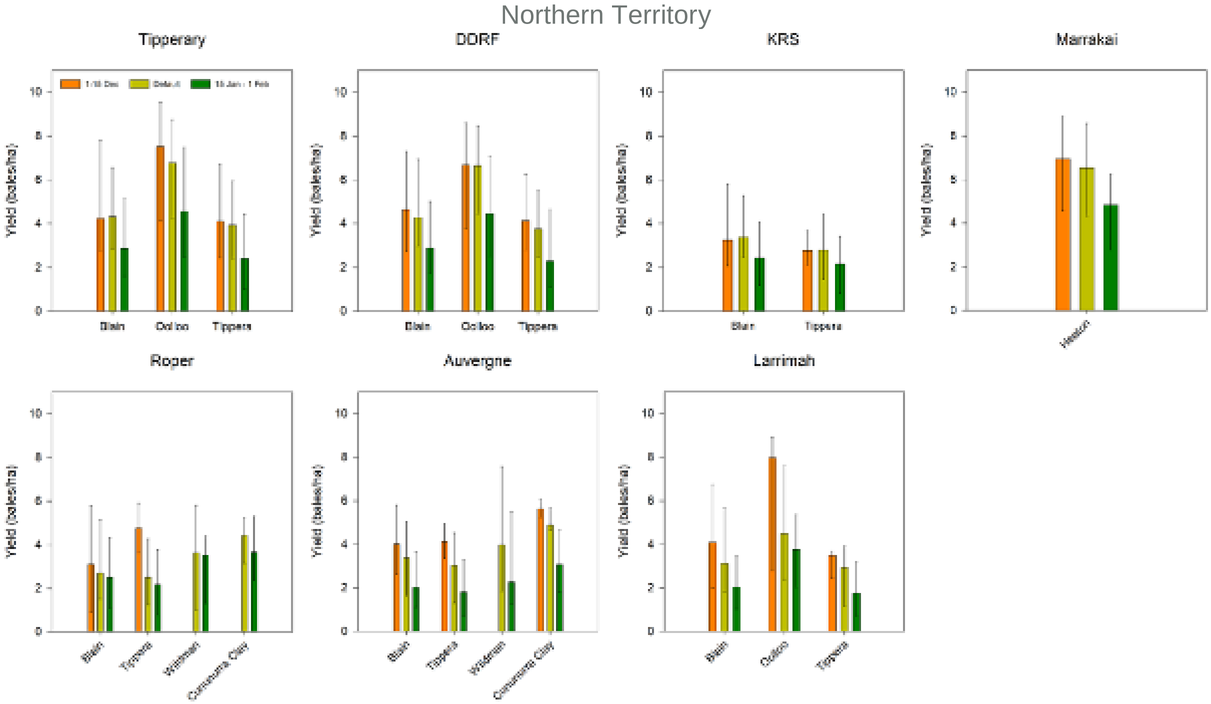

Fig. 2. 8 Simulated rainfed median cotton yields for 1957–2021 and their range (10 to 90% of seasons) within three planting windows 1–15 Dec (early), 15-Dec to 15-Jan (default) and 15-Jan to 1-Feb (late). Simulated yields are for a crop planted on the first day within the sowing window when planting was possible.

2.4.3 Plant Available Water Capacity (PAWC)

Deviations in soil physical properties can be expected across regions. Changes in PAWC was therefore explored under the default simulation settings (planting window 15-Dec to 15-Jan):

- A larger PAWC increased the number of planting opportunities on Kandosols, mostly in the drier production regions (Katherine and south) (Figure 2.9).
- Increases in PAWC over the same soil type improves yield slightly (Figure 2.10).

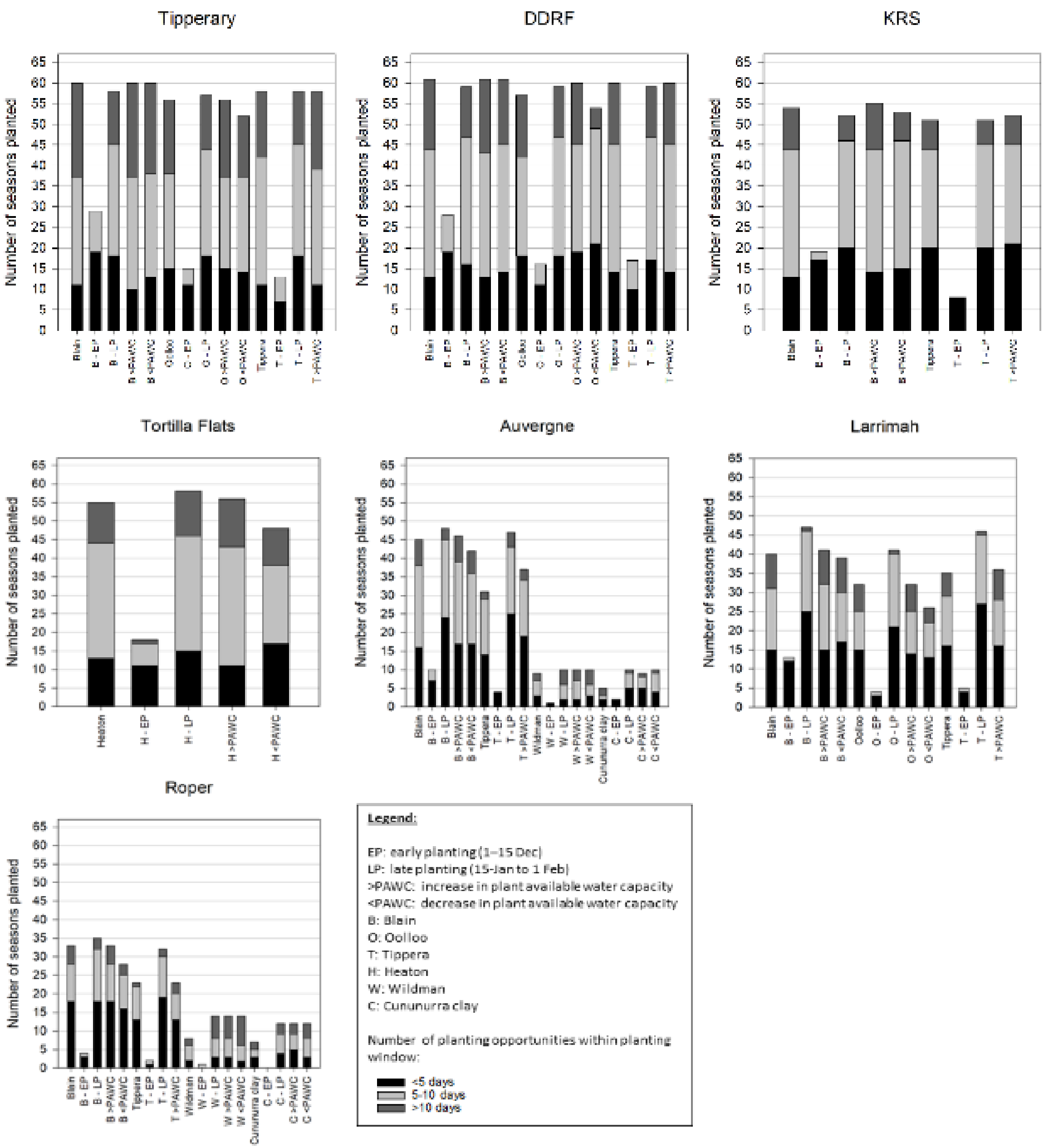

Fig. 2. 9 The number of seasons that were planted (out of 65) for potential cotton growing sites in the Northern Territory under a number of scenarios (default, early planting (1–15 Dec, EP), late planting (15-Jan to 1-Feb, LP), increase in plant available water capacity (**<*PAWC***)) and soil types (Blain (***B***), Oolloo (***O***), Tippera (***T***), Heaton (***H***), Wildman (***W***) and Cununurra clay (***C***)). The stacked bars indicate the number of planting opportunities that occurred within the planting window: <5 days (black), 5–10 days (light grey), >10 days (dark grey).

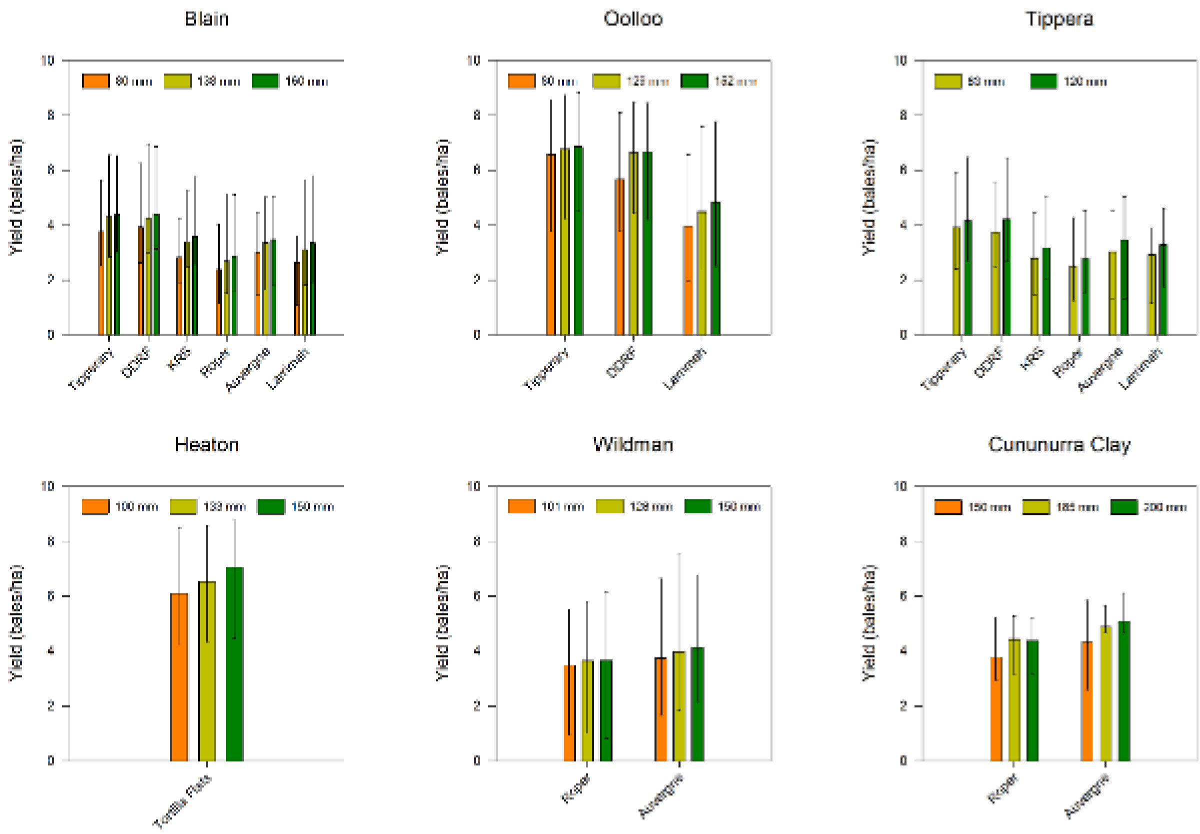

Fig. 2. 10 Simulated rainfed median cotton yields for 1957–2021 and their range (10 to 90% of seasons) grown on a variation in plant available water for several soil types.

2.5 Conclusions

- The planting window that best balances achieved yields and planting opportunities is between 15-Dec and 15-Jan.
- Targeting soils with a larger PAWC (e.g. Oolloo, Blain, Heaton) in the higher rainfall regions (e.g. Daly Basin, Marrakai) show greatest potential for rainfed cotton production in the Northern Territory. Although the simulated yields on Oolloo soils are high based on the limited commercial experience to date.
- An unreasonably low frequency of planting on clay soils due to poor traficability was simulated. The lack of locally validated planting rules would explain this as timely planting was achieved at the Ord river on heavy clays during the wet months (Late January to early March) for several seasons now.
- Simulations for rain grown cotton south of Larrimah – i.e. Northern Barkly (Ucharonidge) indicated unreliable cotton production.
- The APSIM-OZCOT model has not been validated against N uptake on soils in the Northern Territory. This is required to develop N management strategies that best suit the different soil types used in this analysis.

A key question to guide industry development and to support the establishment of local gins in the Northern Territory is what the area of suitable soils in the various regions is, that can be developed for (rainfed) cotton, and the total expected annual production in 10, 50, and 90% of the seasons. While some information and data can be found in online databases (NTGODP, 2022), or reports (TS, 2022), the level of detail required for this analysis cannot be achieved with the data that is currently accessible. While the numbers presented in table 2.4 give a rough estimation, the area that is occupied by the soils presented in this report is unknown.

Table 2. 4 Area of suitable soils (with no access restrictions) in several regions in the Northern Territory that could potentially support (rainfed) cotton production (DITT).

Region	**Area (ha)**
Daly Basin	78,280
Roper Catchment*	1,000–5,000
West Baines	30,179
Sturt Plateau**	5,216
Northern Barkly**	5,234
TOTAL	**119,909 to 123,909**

The numbers presented include the area that is currently developed for agriculture and/or land permitted for clearing.
** Estimate.*
*** Likely to support irrigated cropping only.*

While APSIM-OZCOT was satisfactorily validated for rain grown cotton grown on Kandosol soils in the NT (CRDC and CottonInfo, 2021), results in this report must be used with caution. Since the APSIM-Cotton model (OZCOT) was developed in the temperate cotton growing areas of NSW and southern Queensland, it has consistently failed to adequately predict lint yield of irrigated cotton grown during the wet season in the tropics. Water-stress feedbacks in APSIM-OZCOT are not working correctly and require reparameterization for better simulation in tropical climates (Rhebergen, 2022).

3. Monitoring of Commercial Cotton Fields 2019-20

3.1 Summary

Assessing the natural resource for agriculture cropping potential of commercial cotton production which is a new opportunity for the Northern Territory (NT) is vital. The aim of this research was to measure seasonal soil water and nitrogen availability for cotton, crop growth and yield, then apply the data to support crop management, R&D priorities and assessment of climatic risk and intraregional opportunities. Three rain-grown and 3 irrigated cotton fields were monitored in the Douglas Daly – Tipperary region and a number of measurements including soil cover, soil water and N, crop growth and development, pests and weeds, yield and fibre quality taken from pre planting and at regular intervals until crop destruction. A total of 644 mm of rainfall was received between the months of January to April which was near the long-term median except two fields that recorded below median in March. Soil organic carbon was very low prior to fertiliser application implying limited available of nitrate and hence N supply from these sources for the crop. Water extraction post wet season in rainfed field was measured to a depth of between 180 – 210 cm the maximum sampling depth of the equipment. Post picking sampling was done using a pneumatic soil corer that found roots and dry soil to be between 230 – 300 cm in Oolloo soils and 180 – 240 cm where there were no limitations to roots like rocks. However, future monitoring using deeper coring at the start and end of the growing season was recommended. After picking there was no evidence of soil nitrate accumulation below 150 – 210 cm in any field and nitrate levels remained very low above these depths. Therefore, applying a significant proportion of N fertiliser during the growing season by mid flowering was a successful strategy. Rainfed cotton lint yield ranged between 3.6 – 4.1, while the irrigated was 7.0 – 9.1 b/ha which was an indication of good yield on a first attempt. Fibre quality was at least at the market preference (basis) for the most of lint produced.

3.2 Background

The work reported here was major activity for the cotton component of the collaborative CRCNA project "Potential for broadacre cropping in the NT" in 2020 which required: 1. Assessment of the natural resource (soil, water and climate) to provide for agriculture; 2. Assessment of the cropping potential.

Due to COVID-19 travel restrictions in 2020 interstate collaborators could not visit field sites and assist with data collection for the majority of the cotton season (March to July). Hence key objectives in 2020 were revised.

3.2.1 Measure the available water of key soil types for commercial rain grown & irrigated cotton

The majority of NT soils where cotton could be grown in the short to medium term are well drained "earthy" soils (e.g. Blain, Oolloo, Tippera, Tindal), which are known to have variable (usually low) water availability for a crop. For the majority of these soils the available soil water for cotton has not been measured. Hence, to reliably grow profitable cotton yields (dryland and supplementary irrigated) in the NT environment the soils possessing the greatest availability of water need to be identified. The first step is to measure the water availability to cotton for as many commercial fields as practical and identify the soils and sites with the largest volumes. The next step is to map the location of soils most similar to the best identified.

3.2.2 In commercial fields measure seasonal soil nitrogen availability and cotton removal in key soil types

The better drained soils are inherently unfertile with low organic carbon concentrations; hence fertiliser is likely to be a significant production cost. In the NT the soil depth to which nitrate from fertiliser and organic matter mineralisation is leached is long known to be proportional to the rainfall volume. When seasonal rainfall is significant, and nitrate is present, only deep rooted crops (e.g. pearl millet) can return the leached nitrate to the surface.

Knowing the depth and when cotton roots can extract soil nitrate will improve the efficiency of uptake from fertilisers or previous crop stubble and minimise leaching of nitrate below the root zone, potentially to the wider environment.

3.2.3 On commercial farms commence validation and calibration of the OZCOT-APSIM model for climatic risk assessment of wet season cotton in the NT (rain grown and supplementary irrigated).

A few seasons of trailing cotton commercially in the NT are highly unlikely to capture the between and intra seasonal climatic variability that could impact on cotton production. Regional and intra seasonal variability of rainfall, inconsistent sunlight due to cloud cover and extremes of temperatures will all effect crop growth and potentially the reliability of cotton supply to a gin; the former will also impact on the timing of cropping operations. The OZCOT-APSIM model if validated against locally grown crops and soils can be used to extrapolate production and management scenarios to include the seasonal range observed in the historic climatic record to better quality climatic risk and identify best production regions, soil types and management strategies.

The model has not been validated for cotton grown in the tropical wet season and is likely to require calibration and possibly enhancement for the NT soils and climate.

3.3 General Methods and Measurements

Three rain-grown and three irrigated cotton fields monitored in the Douglas Daly region during the 2019/ 2020 wet season. Measurements were taken in 4 datum areas evenly distributed through the field and representative of the field variability. The following was measured at each datum area:

Climate: Automatic weather station located adjacent to the field or nearest to the field recoded temperature, solar radiation, relative humidity and rainfall.

Mulch cover: Dry weight, species, N%, C%, ground cover %; from 2 m^2 sample area.

Soil nitrate and water: At least 3 times near planting, mid-season, post picking into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments to a depth of between 1.5 and 3.3 depending on equipment available and soil condition at depth. Sampled in plant line and between rows. At the post picking sampling the maximum depth where roots were observed was recorded.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil nitrogen was measured.

Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row on squaring, early and late flowering; Crop maturity by hand picking bolls from 3 m of row weekly from 1st open boll per till 100% open, recording the number and weight of bolls, then calculating the date or 60% open; Lint yield hand-picked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Photo. 3. 1 Left: in crop soil sampling to 2.1 m; Right: post picking coring to > 3m

3.4 Crop Monitoring Reports

3.4.1 Field A – Rain Grown

Methods

Table 3. 1 Field and Crop details

Location / Area / Irrigation system	**Douglas Daly / 40 ha / Dryland**
Soil	Oolloo - sandy clay loam
Previous crop	Jarra Grass
Sowing date / Variety	9-Jan-20 / SC746B3F
Plant population / row width	8.25 plants / m of row. 1m row spacing

Table 3. 2 Applied Fertiliser

			Nutrient Kg/ha								
Date	**Product**	**Rate kg/ha**	**N**	**P**	**K**	**S**	**Zn**	**Cu**	**Ca**	**Mn**	**B**
24/12/19	Basal Mix	125	1.2	20.4	0	5.4	0.13	0	16	0	0.13
25/01/20	Urea / SOP	70	32.2		14.4	6.3					
18/02/20	Compass	150	22.5	9.8	18.8	9.0					
03/03/20	Blend 2	125	33.8		15.6	9.0					
	Total	**505**	**90**	**30**	**49**	**30**	**0.13**	**0.0**	**16**	**0.0**	**0.13**

Table 3. 3 Chemical treatments

Date	Treatment	Chemical Product	Application Rate (L/ha)
5/12/19	Herbicide	Agro	3.3
9/01/20	Herbicide	Gramoxone	3.3
27/01/20	Herbicide	DST Glyphosate	3.3
22/02/20	Herbicide	DST Glyphosate	2.5
22/02/20	Growth reg	Pix	0.3
05/03/20	Growth reg	Pix	1.0

Plus “TraceBrew” 20/2/20 & 7/3/20

Measurements

The following was measured at each datum area:

Climate: Automatic weather station located adjacent to the field recoded temperature, solar radiation, relative humidity and rainfall.

Mulch cover: Dry weight, species, N%, C%, ground cover %; from 2 m^2 sample area.

Soil nitrate and water: To 150 cm on 15 January, 220 cm on 1 April and 16 July and 350 cm on 28 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows. At the 28 July sampling the maximum depth where roots were observed was recorded.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil nitrogen was measured

Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row on 11-February, 10-March and 1 April; Crop maturity by hand picking bolls from 3 m of row weekly from 1st open boll per till 100% open, recoding the number and weight of bolls, then calculating the date or 60% open; Lint yield hand-picked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Photo. 3. 2 On 29 February 20 - Jarra mulch

Results

Climate

Table 3.4 shows rainfall was in bottom 10% for November / December but nearer to the long term (LT) median (50% of years) for January to March, with April double the LT median.

Table 3. 4 Monthly rainfall volumes collected at the site

Month	Observed	LT median
November	57	123
December	56	190
January	204	255
February	276	243
March	122	158
April	42	21

Figure 3.1 shows within season rainfall variability was high particularly for the “critical” period from late February to mid-April.

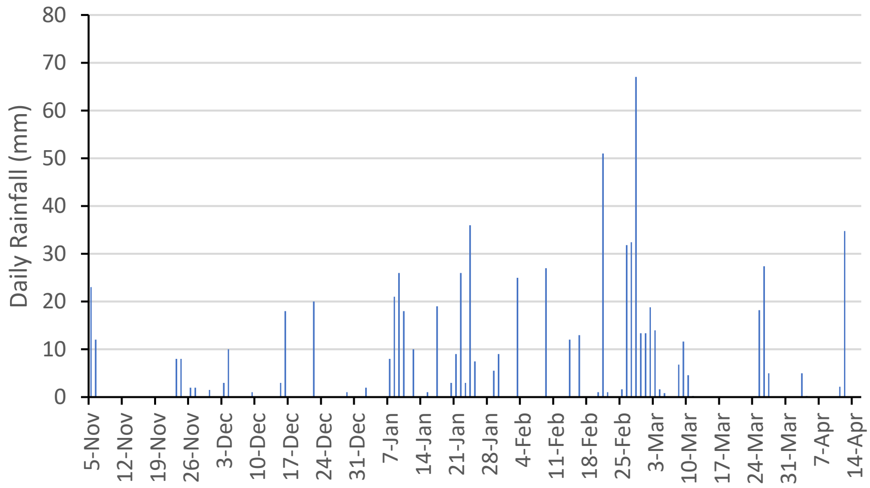

Fig 3. 1 Daily rainfall volumes. Total post planting = 617 mm

Table 3. 5 Average daily solar radiation and temperature

Month	Solar Radiation		Temps max		Temp .min	
	2019/20	LTA	2019/20	LTA	2019/20	LTA
Dec	23	22	38	35	24	24
Jan	19	21	35	34	24	24
Feb	19	21	35	34	25	24
Mar	21	23	36	34	23	23
Apr	21	22	36	35	21	21
May	18	20	33	33	15	17
Jun	20	19	33	32	12	14
Jul	20	20	33	32	10	13

Mulch Cover Properties

Table 3.6 shows soil cover from pervious Jarra grass contained 100 N kg/ha however the C:N ratio was high and effectively no N fertiliser was applied until 16 days after planting (Table 3.2), hence decomposition was slow and would have tied up some soil N.

Table 3. 6 Mulch Cover details

Cover	Date	% Cover	DW kg/ha (se)	% C	% N	N kg/ha	C/N
Jarra Grass	24-dec-19	98	7327	42.0	1.36	100	45.3

Soil Properties: Water, Nitrate and Organic Carbon

Table 3.7 shows near sowing soil organic carbon and soil nitrate were very low (12 kg N/ha) and common for these soils. Indicating crop N supply from these sources would be very limited.

Table 3. 7 Soil water, nitrate, and organic carbon soon after sowing (15-Jan-20). NT = not tested

Soil Depth Range (cm)	Gravimetric Soil Water (%)	Nitrate (mg/kg)	Organic Carbon (%)
0 to 15	8	4	0.39
15 to 30	10	3	0.23
30 to 60	12	6	
60 to 90	14	1	
90 to 120	13	1	
120 to 150	11	NT	

Table 3.8 shows soil nitrate measured to 210 cm declined from sowing to maturity indicating plant removal, although there was a small accumulation by April 1 between 60 and 150 cm. Between 180 and 350 cm soil nitrate was near the lowest concentration for detection hence deep leaching did not occur.

Table 3. 8 Seasonal change in soil nitrate by depth

Soil Depth Range (cm)	Nitrate (mg/kg)		
	15-Jan-20	1-Apr-20	16 & 27-Jul-20
0 to 15	4.3	0.8	1.3
15 to 30	2.5	1.6	1.1
30 to 60	5.6	0.8	1.0
60 to 90	1.1	3.4	1.6
90 to 120	1.3	4.5	2.5
120 to 150		3.0	2.5
150 to 180		1.1	1.8
180 to 210		0.5	1.0
210 to 240			0.7
240 to 270			1.0
270 to 300			0.5
300 to 330			0.8
330 – 350			0.5

Seasonal change in soil water and depth of water extraction.

Figure 3.2 shows soil water peaked on March 3 and crop extraction of water was measured to 210 cm at maturity. Unfortunately sampling to > 210 cm at peak soil water in March was not possible in 2020 so the volume of water extracted below this depth could not be measured. Roots were observed between 260 and 300 cm in soil cores taken after picking, although finding roots using a 50 mm corer can be hit and miss so these depths are an estimate of the maximum depth.

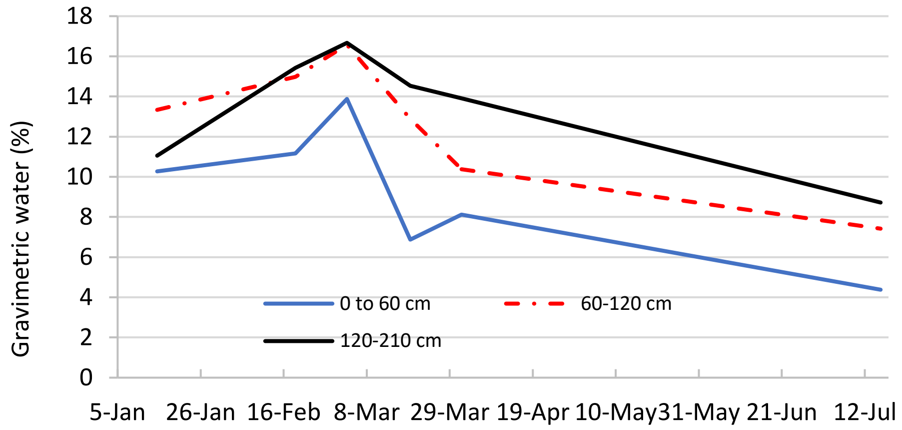

Fig 3. 2 Seasonal change in gravimetric soil water (%) with soil depth

Photo. 3. 3 On 1 April 2020 – premature senescence like symptoms on leaves

Crop Details

Table 3.9 shows Leaf area development was rapid and typical for wet season cotton, peaking 82 days after planting and near to canopy closure. Boll retention was high leading to rapid boll opening, early maturity and leaves with symptoms of premature senescence, the later probably due to boll demand for potassium exceeding the plant's capacity to supply. Lint yield averaged 4.1 b/ha for the datum areas picked, without quality discount.

Table 3. 9 Crop development, leaf area, boll retention, open bolls, Yield, lint %, fibre quality

Crop Development	1st square 11-Feb; 1st Flower 5-Mar, Cut-out 12-Apr; 1st Open Boll 20-Apr 60% Open 29-Apr; 100% open 18-May Picking 25-June
Final Height / node number	78 cm ± 0.2.1 / 18 nodes ± 0.3
Final open boll number	76 / m^2 ± 3.72
Boll retention	53.4 % ± 0.51
Maximum Leaf Area Index / date (m^2 leaf per m^2 soil surface)	2.7 ± 0.13 / 1-April
Average Yield 4 datum areas (bales / ha)	4.1 (± 0.51)
Lint %	42
Fiber quality	Basis = no discount

Key Findings Field A

- In-crop rainfall (January to April) was near the long-term median
- Soil organic carbon and available nitrate was very low at planting. Indicating crop N supply from these sources would be very limited.
- While the Jarra cover contained 100 kg N/ha, the C:N ratio was high, hence decomposition was slow and would have tied up some soil N early in the season.
- Soil water peaked on March 3 and crop extraction of water was measured to 210 cm at maturity.
- Roots were observed between 260 and 300 cm in soil cores taken after picking. Unfortunately sampling to > 210 cm at peak soil water in March was not possible in 2020 so the volume of water extracted below this depth at picking could not be measured; it will be measured for this field in 2021.
- There was a small accumulation of soil nitrate between 60 and 150 cm by April 1. However, after picking nitrate concentrations to 350 cm were extremely low indicating effective crop removal and deep leaching did not occur.
- Leaf area development was rapid and typical for wet season cotton, peaking 82 days after planting.
- Boll retention was high leading to rapid boll opening, earlier maturity and leaves with symptoms of premature senescence; the later probably due to boll demand for nutrients exceeding the plant’s capacity to supply.
- Average lint yield from the datum areas was 4.1 b/ha without quality discount.

3.4.2 Field B – Rain Grown

Methods

Table 3. 10 Field and Crop details

Location / Area / Irrigation	Douglas Daly / 40 ha / Dryland
Soil	Oolloo - sandy clay loam
Previous crop	Sorghum
Sowing date / Variety	12 January 20 / SC746B3F
Plant population / row width	8.1 plants / m (variable) of row. 1m row spacing

Table 3. 11 Applied Fertiliser

Date	Product	Rate kg/ha	N	P	K	S	Zn	Cu	Ca	Mn	B
					Nutrient	Kg/ha					
24/12/19	Basal Mix	125	1.2	20.4	0	5.4	0.13	0	16	0	0.13
25/01/20	Urea / SOP	70	32.2		14.4	6.3					
18/02/20	Compass	150	22.5	9.8	18.8	9.0					
03/03/20	Blend 2	125	33.8		15.6	9.0					
	Total	**505**	**90**	**30**	**49**	**30**	**0.13**	**0.0**	**16**	**0.0**	**0.13**

Table 3. 12 Chemical treatments

Date	Treatment	Chemical Product	Application Rate (L/ha)
5/12/19	Herbicide	Agro	3.3
9/01/20	Herbicide	Gramoxone	3.3
27/01/20	Herbicide	DST Glyphosate	3.3
22/02/20	Herbicide	DST Glyphosate	2.5
22/02/20	Growth reg	Pix	0.3
05/03/20	Growth reg	Pix	1.0

Plus “TraceBrew” 20/2/20 & 7/3/20

Measurements

Due to variable crop establishment many planned plant measurements requiring a uniform plant population were not taken.

Climate: Rainfall at the field. An automatic weather station located 5 km from the field recoded temperature, solar radiation and relative humidity.

Mulch cover: Dry weight, species, N%, C%, ground cover % on 24/12/19; from 2 m^2

Soil Nitrate and water: To 150 cm on 16 January, 220 cm on 16 July and 350 cm on 28 July. Water only on 18 February to 150 cm. Separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil Nitrogen was measured.

Plant measurements: Lint yield hand-picked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Photo. 3. 4 On 16-January-20: Soil sampling at planting, note patchy ground cover.

Photo. 3. 5 On 16-January-20: Soil surface crust and seedlings prior to emergence

Photo. 3. 6 On 28 July 2020 post picking coring to > 3m

Results

Climate

Figure 3.3 shows in crop rainfall was 463 mm with February and April being near to the long-term median (50% of seasons) and March about half the median. The largest rainfall events were from late February to early March.

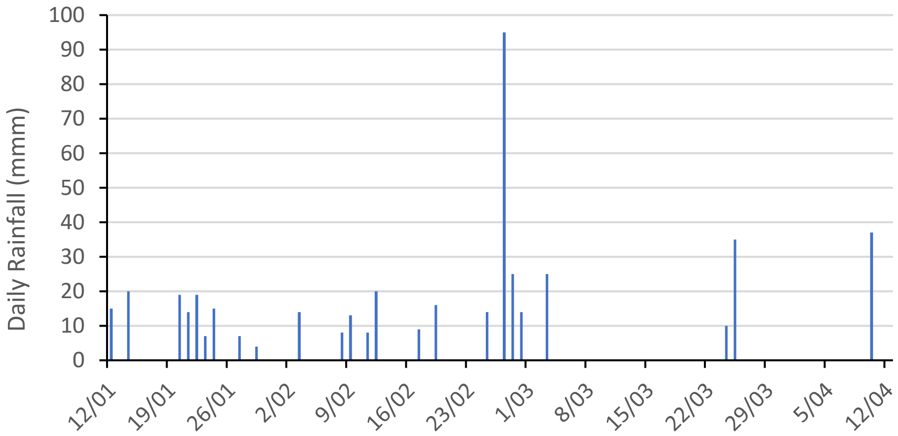

Fig 3. 3 Daily Rainfall volumes (Total 463 mm)

Table 3. 13 Average daily solar radiation and temperature

	Solar Radiation		Temps max		Temps min	
	2019/20	LTA	2019/20	LTA	2019/20	LTA
Dec	23	22	38	35	24	24
Jan	19	21	35	34	24	24
Feb	19	21	35	34	25	24
Mar	21	23	36	34	23	23
Apr	21	22	36	35	21	21
May	18	20	33	33	15	17
Jun	20	19	33	32	12	14
Jul	20	20	33	32	10	13

Mulch cover properties

Table 3.14 shows grain sorghum stubble from the previous wet season was variable and well decomposed prior to planting.

Table 3. 14 Mulch Cover details

Cover	Date Sampled	% Cover	DW kg/ha	% Carbon	% N	N kg/ha	C/N
Grain sorghum stubble 2019	24-dec-19	49	2215	43.45	0.85	19	39.9

Soil properties: Water, nitrate and organic carbon

Table 3.15 shows organic carbon was low for the growing season and typical for these soils. Soil nitrate concentrations were reasonable at sowing; equivalent to about 45 kg N/ha; decomposition of sorghum stubble from the previous season would have contributed to soil nitrate. By crop maturity there was a small accumulation of nitrate at 150 cm and possibly to 210 cm. Between 240 and 350 cm soil nitrate was near the lowest concentration for detection hence deep leaching did not occur.

Table 3. 15 Soil Nitrate and Organic Carbon after sowing (January) and after picking (July)

Soil Depth Range (cm)	Nitrate (mg/kg)		Organic Carbon (%)	
	16-Jan	16 & 28 July	16-Jan	16 & 28 July
0 to 15	4.1	1.5	0.37	0.37
15 to 30	8.8	3.0	0.24	0.28
30 to 60	15.3	3.6		
60 to 90	8.1	4.8		
90 to 120	8.4	7.3		
120 to 150	6.3	9.1		
150 to 180		5.8		
180 to 210		7.0		
210 to 250		3.9		
240 to 270		1.5		
270 to 300		1.3		
300 to 330		1.0		
330 to 350		0.6		

Seasonal change in soil water and depth of water extraction

Roots were observed to 230 cm in soil cores taken after picking, although finding roots using a 50 mm corer can be hit and miss so this depth is an estimate of the maximum depth. Figure 3.4 shows soil water was removed to a depth of 150 cm by picking. After picking soil water found the soil to be dry at 350 cm. Unfortunately, sampling below 150 cm prior to picking was not possible in 2020 so any water extracted by below this depth by picking could not be measured.

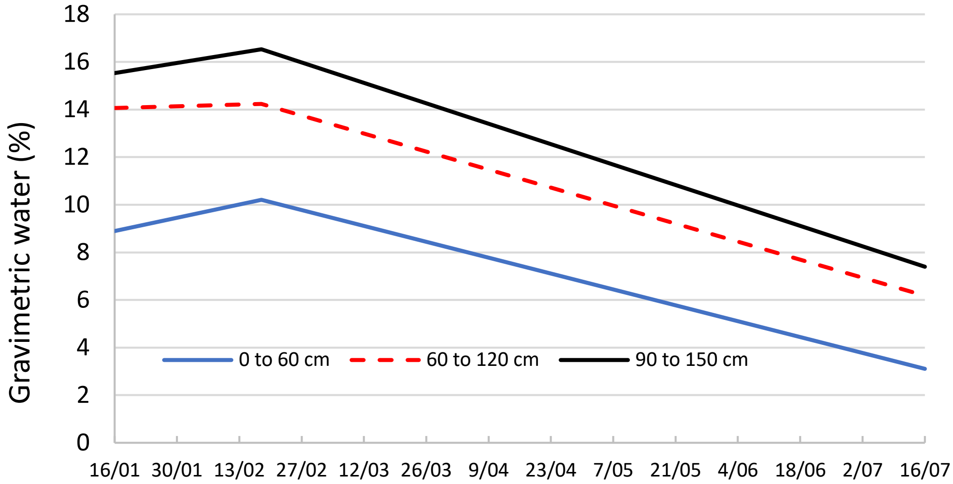

Fig 3. 4 Change in gravimetric soil water (%) with soil depth

Photo. 3. 7 On 28-May-20: Maturity

Crop Details

Hand-picked yields were variable as expected. Yields from some uniform areas of crop were good (> 5 bales/ha)

Table 3. 16 Crop development, leaf area, boll retention, open bolls, Yield, lint %, fibre quality

Crop Development	1st square 18-Feb; 1st Flower 9-Mar, Defoliation 28-May and Picking 24-June
Yield (bales / ha)	Hand-picked in uniform areas 4.5 (± 0.8) and Field machine picked 3.6
Lint %	36.19
Fiber quality	Basis = no discount

Key Findings - Field B

- Planting was on 12-Jan-20; variable sorghum stubble cover resulted in soil surface crusting in bare areas and a patchy crop establishment. Hence many plant measurements requiring a uniform plant population were not taken.
- In crop rainfall was 463 mm with February and April being near to the long-term median and March about half the median.
- Organic carbon was low for the growing season and typical for these soils.
- Soil nitrate concentrations at planting were equivalent to 45 kg N/ha to 150 cm; decomposition of sorghum stubble from the previous season would have contributed to soil nitrate.
- After picking a small accumulation of soil nitrate was measured between 150 and 210 cm. Between 240 and 350 cm soil nitrate was near the lowest concentration for detection hence deep leaching did not occur.
- Roots were observed to 230 cm in soil cores taken after picking, although finding roots using a 50 mm corer can be hit and miss so this depth is an estimate of the maximum.
- After picking the soil was dry to 350 cm. Unfortunately sampling below 150 cm prior to picking was not possible in 2020 hence any water extracted by below this depth could not be measured.
- As expected, hand-picked yields where variable with some uniform areas were > 5 bales/ha. Machine picked yield was 3.6 b/ha without quality discount.

3.4.3 Field C - Rain Grown

Methods

Table 3. 17 Field and Crop details

Location / Area / Irrigation	Tipperary / 200 ha / Dryland
Soil	Tippera – clay loam
Previous crop	Mixed – grass dominant
Sowing date / Variety	15-Dec-19 / SC746B3F & SC748B3F Monitoring area 1 - SC746B3F, 2 to 4 - SC748B3F
Plant population / row width	9 plants / m of row. 1m row spacing

Inputs

The following inputs were provided by the grower are shown in Tables 3.18 and 3.19.

Table 3. 18 Applied Fertiliser

					Nutrient	Kg/ha					
Date	**Product**	**Rate kg/ha**	**N**	**P**	**K**	**S**	**Zn**	**Cu**	**Ca**	**Mn**	**B**
20/11/2019	Basal Mix	150	15	31.5		6	1.5				
6/01/2020	Blend	125	33.8	5.6	5.6	7.9	0.25	0.163	0.2	0.13	0.003
14/02/2020	Quick N	150	39			22.5					
3/03/2020	Blend	150	40.5	6.8	6.8	9.5	0.3	0.195	0.24	0.15	0.003
3/04/2020	Blend	150	40.5	6.8	6.8	9.5	0.3	0.195	0.24	0.15	0.003
	Total	**725**	**169**	**51**	**19**	**55**	**2.4**	**0.6**	**0.7**	**0.4**	**0.01**

Table 3. 19 Chemical treatments

Date	Glyphosate	Pix
28/01/2020	Yes	0.25 lt/ha
18/02/2020	Yes	
2/03/2020		0.3 lt/ha
24/03/2020		0.6 lt/ha

Measurements

The following was measured at each datum area:

Climate: Rainfall at the field. Temperature and solar radiation from automatic station 27 km SSE.

Mulch cover: Mulch species and a visual assessment of percentage of soil cover was recoded when monitoring commenced about two months after planting.

Soil Nitrogen: To 150 cm on 24 February, 4 March and 180 cm on 8 April and 390 cm on 27 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows.

Soil Water: To 150 cm on 24 February, 4 March and 20 March; 180 cm on 8 April and between 270 and 390 cm (depth to rock) on 27 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil Nitrogen was measured

Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row on 4-March, 7-April and 12 May; Crop maturity by hand picking bolls plant 3 m of row weekly from 1st open boll per till 100% open, recoding the number and weight of bolls, then calculating the date or 60% open; Lint yield handpicked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Results

Climate

Table 3. 20 Growing season rainfall.

Date	Rain (mm)
12 to 17/12/19	40
21/01/20	65
11/02/20	24
18/02/20	70
20/02/20	50
27/2 to 1/3/20	186
9/03/20	45
16/03/20	36
10/04/20	55

Table 3. 21 Average daily solar radiation (MJ/m2) and temperature LTA = Long Term Average.

	Solar Radiation		Tmax		Tmin	
	2019/20	LTA	2019/20	LTA	2019/20	LTA
Dec	23	22	38	35	24	24
Jan	19	21	35	34	24	24
Feb	19	21	35	34	25	24
Mar	21	23	36	34	23	23
Apr	21	22	36	35	21	21
May	18	20	33	33	15	17
Jun	20	19	33	32	12	14
Jul	20	20	33	32	10	13

Figure 3.5 shows daily solar radiation was mostly favorable for this crop as there were only brief periods of low radiation after flowering (late March) due to cloud in 2020

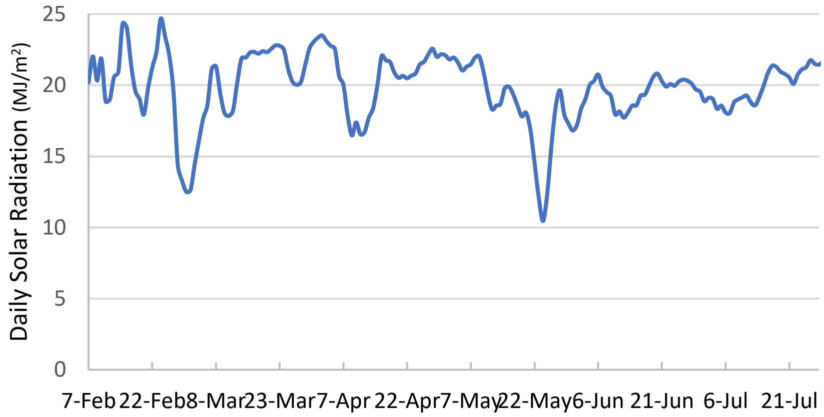

Fig 3. 5 Daily solar radiation for the growing season (shown as a 4 day moving average)

Photo. 3. 8 On 5 March 20 – large leafy plants at early flowering

Soil properties: Water, nitrate and organic carbon

Table 3.22 shows soil organic carbon and nitrate N were low (14 kg N/ha) 71 days after planting and typical for this soil. Note nearly half the fertiliser N was applied after these soil samples were taken

Table 3. 22 Soil water, nitrate and organic carbon 24-Feb-20

Soil Depth Range (cm)	Gravimetric Soil Water (%)	Nitrate (mg/kg)	Organic Carbon (%)
0 to 15	17	9	0.87
15 to 30	15	3	0.34
30 to 60	16	3	
60 to 90	16	3	
90 to 120	17	2	
120 to 150	21	1	

Table 3.23 shows soil nitrate declined to extremely low concentrations by maturity when they were negligible to 300 cm; indicating the crop removed nitrate and deep leaching did not occur.

Table 3. 23 Seasonal change in soil nitrate by depth.

Soil Depth Range (cm)	Nitrate (mg/kg)		
	4-Mar-20	8-Apr-20	27-Jul-20
0 to 15	2.5	2.2	1.3
15 to 30	0.9	1.4	0.5
30 to 60	2.3	1.1	0.5
60 to 90	2.1	0.7	0.5
90 to 120	2.8	0.5	0.5
120 to 150	0.5	0.6	0.5
150 to 180		0.8	0.5
180 to 210			0.5
210 to 240			0.5
240 to 270			0.5
270 to 300			0.5

Note due to rocks in sub soil the maximum depth of sampling on 27 July for the four datum areas was 390 cm, 240 cm, 120 cm, 270 cm with all < 1 mg/kg nitrate at maximum depth.

Photo. 3. 9 On 7 April 20 – large plant shedding fruit

Seasonal change in soil water and depth of water extraction

Figure 3.6 shows soil water peaked on March 4 after which the crop removed soil water to 180 cm until maturity. Soil depth, measured after picking, was variable between 120 cm and 390 cm due to rock or too wet to remove cores above rock. Roots were found between 70 cm and 240 cm depending on depth to rock. Note finding roots using a 50 mm corer can be hit and miss so these depths are an estimate of the maximum depth.

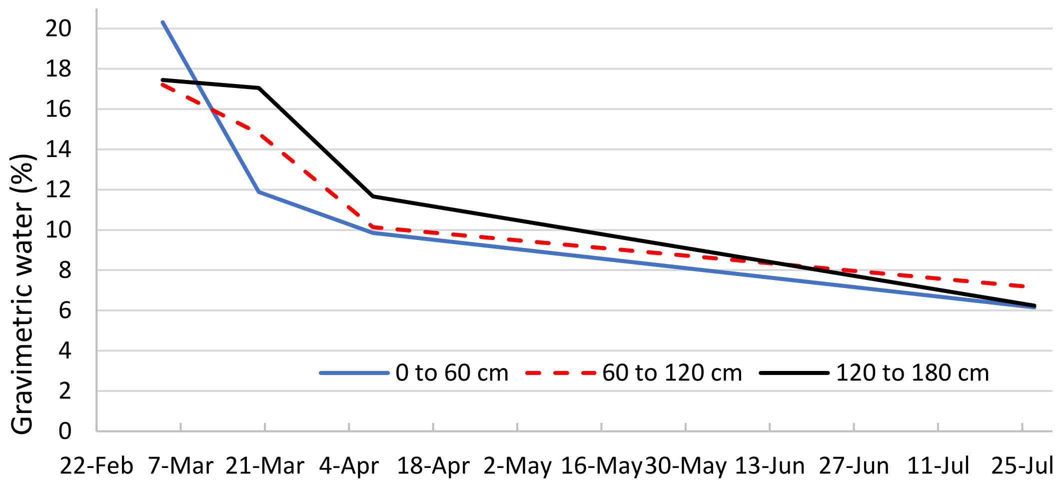

Fig 3. 6 Change in gravimetric soil water (%) with soil depth

Photo. 3. 10 On 8 July 20 – Maturity

Crop details

Table 3.24 shows fruit shedding reduced boll retention and contributed to a tall and leafy crop. Yield averaged 3.7 b/ha for the four datum areas. Fiber quality was basis or above for most bales produced.

Table 3. 24 Crop development, leaf area, boll retention, open bolls, Yield, lint %, fibre quality

Crop Development	1st square NA; 1st Flower 24-Feb, Cut-out 31-Mar; 1st Open Boll 17-Apr 60% Open 9-May; 100% open 2-June
Final Height / node number	131 cm ± 1.5 / 23 nodes ± 0.3
Final open boll number	49 / m^2 ± 1.9
Boll retention	31.1 % ± 0.20
Maximum Leaf Area Index / date (m^2 leaf per m^2 soil surface)	3.8 ± 0.44 / 1-April
Yield (bales / ha)	3.7 ± 0.54
Lint %	41.3#
Datum area fibre quality	Basis or above

Key findings - Field C

- Planted on 15 December 2020
- Soil organic carbon and nitrate N were low (14 kg N/ha) 71 days after planting and typical for this soil. Note nearly half the fertiliser N was applied after these soil samples were taken.
- Soil nitrate declined to extremely low concentrations by maturity when they were negligible to 300 cm indicating the crop removed nitrate and deep leaching did not occur.
- Soil water peaked on March 4 after which the crop removed soil water to an average depth of 180 cm until maturity. Unfortunately sampling to > 180 cm at peak soil water in March was not possible in 2020 so the volume of water extracted below this depth at picking could not be measured.
- Soil depth, measured after picking, was variable between 120 cm and 390 cm due to rock or soil to wet to remove cores above rock. Roots were found between 70 cm and 240 cm depending on depth to rock.
- Fruit shedding reduced boll retention, common to wet season cotton, contributed to a tall and leafy crop. Yield compensation to fruit loss via latter pollinated flowers would have delayed maturity
- Yield averaged 3.7 b/ha for the four datum areas. Fibre quality was basis or above for most bales.

3.4.4 Field D - Irrigated

Methods

Table 3. 25 Field and crop details

Location/ Area / Irrigation system	40 ha Pivot
Soil	Oolloo - sandy clay loam
Previous crop	Pop Corn
Sowing date / Variety	31-Jan 2020 / SC746B3F
Plant population / Row width	9.6 plants / m of row. 1m row spacing

Inputs

Table 3. 26 Fertiliser

Date	Product	Rate kg/ha	Nutrient Kg/ha N	P	K	S	Zn	Cu	Ca	Mn	B
30/01/2020	Basal+B1	280	42	28	7	15	0.4	0.2	16	0.2	0.2
16/02/2020	Compass	150	23	10	19	9					
3/03/2020	Blend 2	125	34		16	9					
15/04/2020	Compass	150	22	10	19	9					
	Total	**705**	**121**	**47**	**60**	**42**	**0.4**	**0.2**	**16**	**0.2**	**0.2**

Table 3. 27 Chemical treatments

Date	Treatment	Chemical Product	Application Rate (L/ha)
19/12/2019	Herbicide	Agro	3.1
4/03/2020	Herbicide	DST Gly	3.5
6/03/2020	Growth Reg	Pix	0.4
28/03/2020	Growth Reg	Pix	1

Trace Brew 6/3/20 & 28/3/20

Measurements

The following was measured at each datum area:

Climate: Rainfall at the field. Temperature, solar radiation and relative humidity were recorded by automatic weather station located in an adjacent field (500m).

Mulch cover: Dry weight, species, N%, C%, ground cover %; from 2 m^2 .

Soil Nitrate and water: To 150 cm on 15 January, 220 cm on 1 April and 16 July and 330 cm on 28 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil nitrogen was measured.

Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row on 11-February, 10-March and 1 April; Crop maturity by hand picking bolls plant 3 m of row weekly from 1st open boll per till 100% open, recoding the number and weight of bolls, then calculating the date or 60% open; Lint yield hand-picked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Results

Climate

Table 3.28 shows in-crop rainfall near to the long term (LT) median (50% of years) for February and March and double the LT median in April.

Table 3. 28 Monthly rainfall volumes

Month	Observed	LT median
November	57	124
December	56	190
January	204	257
February	274	240
March	132	158
April	34	21

Total rainfall November to April = 756mm. Irrigation volumes were not recorded preventing use of this site for cotton model validation.

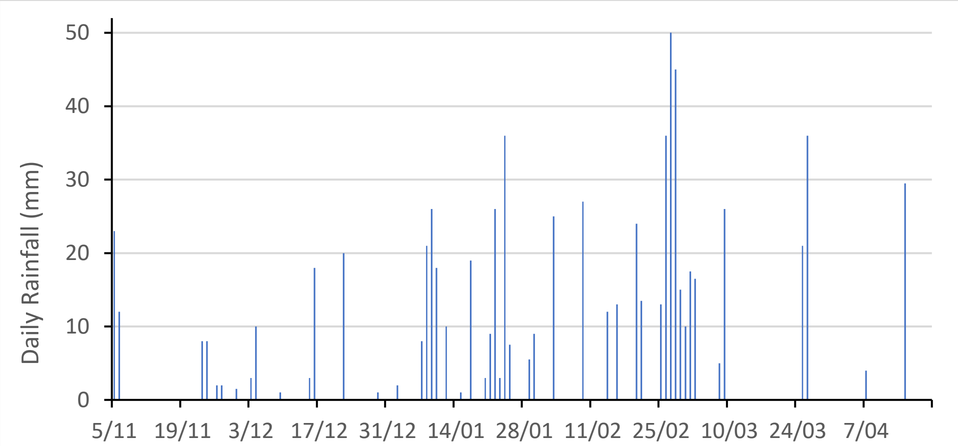

Fig 3. 7 Daily Rainfall

Temperature and solar radiation

Table 3. 29 Average daily solar radiation and temperature

	Solar Radiation		Temps max		Temps min	
	2019/20	LTA	2019/20	LTA	2019/20	LTA
Dec	23	22	38	35	24	24
Jan	19	21	35	34	24	24
Feb	19	21	35	34	25	24
Mar	21	23	36	34	23	23
Apr	21	22	36	35	21	21
May	18	20	33	33	15	17
Jun	20	19	33	32	12	14
Jul	20	20	33	32	10	13

Figure 3.8 shows daily solar radiation was mostly favorable for this crop as there were only brief periods of low radiation after flowering (late March) due to cloud in 2020.

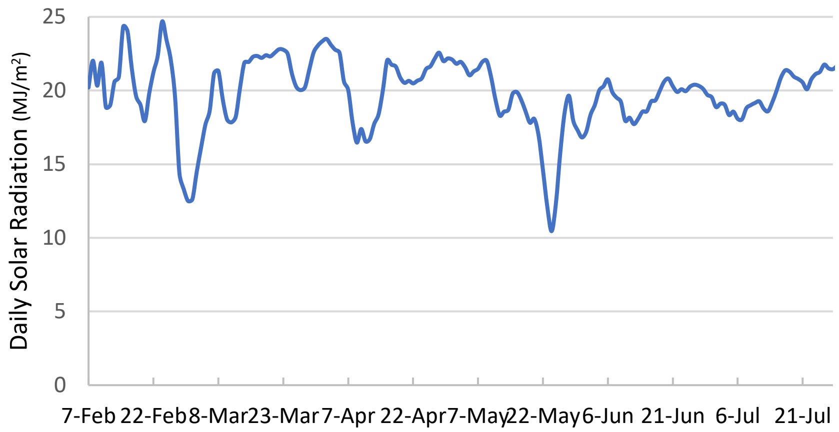

Fig 3. 8 Daily solar radiation for the growing season (shown as a 4 day moving average).

Mulch Cover Properties.

Table 3.30 shows the popcorn mulch contained 54 kg/ha of N however the C:N ratio was high and could have tied up some soil and fertiliser N early in the season.

Table 3. 30 Mulch Cover details

Cover	**Date Sampled**	**% Cover**	**DW** kg/ha	**% Carbon**	**N %**	**N** kg/ha	**C/N**
Pop corn	24-Dec-19	78	6366	41.2	0.85	54	48.5

Photo. 3. 11 Soil cover at establishment, 6 February 2020

Soil Properties: Water, Nitrate and Organic Carbon.

Table 3.31 shows soil nitrate soon after planting was equivalent to 59 kg N/ha and mostly in the surface 90 cm, due to fertiliser application. Soil organic carbon was low compared to most soils in temperate Australia but higher than usually observed on Oolloo soil in the NT.

Table 3. 31 Soil water, nitrate and organic carbon soon after sowing (10-Feb-20)

Soil Depth Range (cm)	Gravimetric Soil Water (%)	Nitrate (mg/kg)	Organic Carbon (%)
0 to 15	18	27	0.92
15 to 30	15	19	0.47
30 to 60	17	14	
60 to 90	18	13	
90 to 120	19	5	
120 to 150	19	3	

Photo. 3. 12 On 8-May-2020: In-crop soil sampling

Table 3.32 shows that by 8-May the crop had depleted to soil nitrate to 90 cm. Soil nitrate concentrations were extremely low after picking. Between 120 cm and 330 cm soil nitrate was near the lowest concentration for detection indicating deep leaching did not occur.

Table 3. 32 Seasonal change in soil nitrate by depth.

Soil Depth Range (cm)	Nitrate (mg/kg)		
	10-Feb	8-May	29-July
0 to 15	27	2.6	0.9
15 to 30	19	0.6	0.6
30 to 60	14	1.1	0.9
60 to 90	13	3.3	1.9
90 to 120	5	4.9	2.6
120 to 150	3	2.6	1.8
150 to 180			1.0
180 to 210			0.9
210 to 240			0.8
240 to 270			0.6
270 to 300			0.6
300 to 330			0.5

Seasonal change in soil water and depth of water extraction.

Roots were observed to 270 cm in soil cores taken after picking, although finding roots using a 50 mm corer can be hit and miss so these depths are an estimate of the maximum depth. Unfortunately sampling to > 210 cm at peak soil water in March was not possible in 2020 so the volume of water extracted by the crop below this depth at picking could not be measured. Figure 3.9 shows soil water peaked on March 3 and crop removal continued to a depth of 210 cm until May 8. Regular irrigation limited the amount of water extracted after this time.

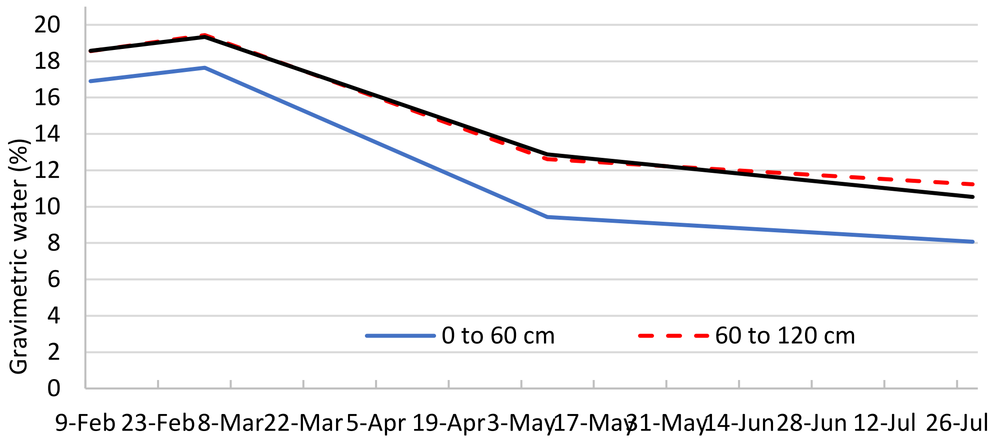

Fig 3. 9 Change in gravimetric soil water (%) with soil depth

Photo. 3. 13 At maturity stage

Crop Details

Table 3.33 shows, leaf area development was rapid with leaf area index > 3 early in flowering (55 days after planting); common for irrigated cotton sown mid wet season. Yield averaged 9.1 b/ha for the four datum areas picked. For the majority of bales produced fiber quality was good (basis or above).

Table 3. 33 Crop development, leaf area, boll retention, open bolls, yield, lint %, fibre quality

Crop Development	1st square 28-Feb; 1st Flower 18-Mar, Cut-out 21-Apr; 1st Open Boll 13-May 60% Open 20-Jun; 100% open 15-July
Final Height / node number	118 cm ± 1.3 / 23 nodes ± 0.4
Final open boll number	112 / m^2 ± 4.04
Boll retention	30.5% ± 0.60
Date Leaf Area Index > 3 Maximum Leaf Area Index / date (m^2 leaf per m^2 soil surface)	26 – Mar 4.5 ± 0.40 / 7-May
Average yield 4 datum areas (bales / ha)	9.1 ± 0.51
Lint %	42
Fibre quality	Basis or above

Key Findings Field D - HI

- In-crop rainfall near to the long-term median (50% of years) for February and March and double the median in April.
- Daily solar radiation, critical for irrigated cotton, was mostly favorable with only brief periods of low radiation after flowering (late March) due to cloud.
- Soil nitrate soon after planting was equivalent to 59 kg N/ha and mostly in the surface 90 cm due to fertiliser application. By 8-May the crop had depleted soil nitrate.
- Soil nitrate concentrations were extremely low after picking. Between 120 and 330 cm soil nitrate was near the lowest concentration for detection indicating deep leaching did not occur.
- Soil water peaked on March 3 and crop removal continued to a depth of 210 cm until May 8. Regular irrigation limited the amount of water extracted after this time.
- Roots were observed to 270 cm in soil cores taken after picking; finding roots using a 50 mm corer can be hit and miss so this depth is an estimate of the maximum.
- Leaf area development was rapid with canopy closure by early flowering: common for irrigated cotton sown mid wet season.
- Yield averaged 9.1 b/ha for the four datum areas picked. For the majority of bales produced fiber quality was basis or above.

3.4.5 Field E - Irrigated

Measurements

The following was measured at each field or datum area:

Climate: Rainfall at the field. An automatic weather station located 5 km from the field recoded temperature, solar radiation and relative humidity.
Mulch cover: Dry weight, species, N%, C%, ground cover %; from 2 m^2
Soil Nitrate, Ammonium and water: To 150 cm on 10 Feb and 14 May and 300 cm on 28 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows. At the 28 July sampling the maximum depth where roots were observed was recorded.
Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil Nitrogen was measured
Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row squaring, early flowering, cut-out and 60% open bolls; Date of crop maturity by hand picking bolls from 3 m of row weekly from 1st open boll per till 100% open; Lint yield hand-picked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Results

Climate

Table 3.34 shows monthly rainfall was near to the long term (LT) median (50% of years) in February well below in March and above in April

Table 3. 34 Monthly rainfall volumes (mm) recorded at the field

Month	Observed	LT median
February	236	240
March	70	158
April	37	21

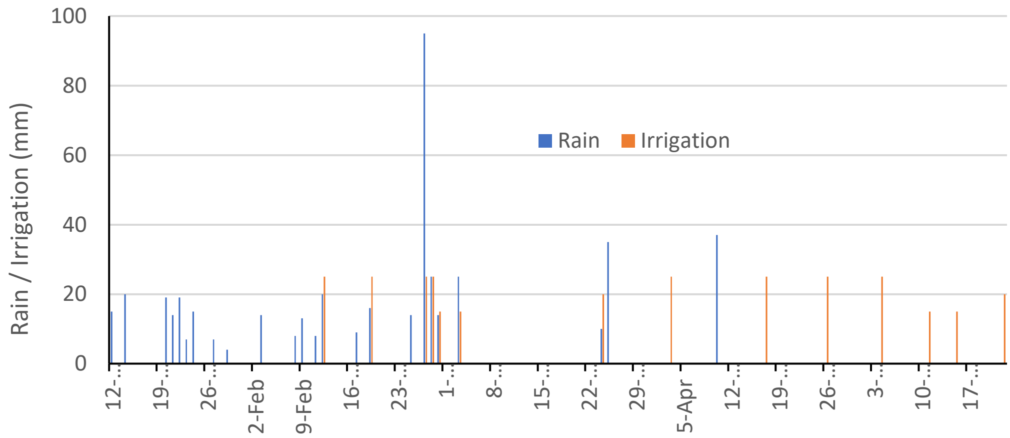

Fig 3. 10 Daily Rainfall and Irrigation volumes. Total rainfall post planting (6-Feb) was 463mm and total Irrigation 300 mm.

Table 3. 35 Average monthly temperatures compared to the long term average (LTA)

	Temps max		Temps min	
	2019/20	LTA	2019/20	LTA
Dec	38	35	24	24
Jan	35	34	24	24
Feb	35	34	25	24
Mar	36	34	23	23
Apr	36	35	21	21
May	33	33	15	17
Jun	33	32	12	14
Jul	33	32	10	13

Figure 3.11 shows daily solar radiation was mostly favorable for this crop as there were only brief periods of low radiation after flowering (late March) due to cloud in 2020

Fig 3. 11 Daily solar radiation for the growing season (shown as a 4 day moving average)

Mulch Cover Properties

Table 3.36 shows forage sorghum cover had double the biomass and N as Rhodes cover. However, being grass species the C:N ratio was high and greatest for the Rhodes grass hence decomposition was sow and would have tied up some soil and fertiliser N early in the season.

Table 3. 36 Mulch Cover details

Cover	**Date Sampled**	**Ground Cover %**	**Dry weight** kg/ha	**Carbon %**	**N %**	**N** kg/ha	**C/N**
Rhodes	13-Jan-20	100	7635	43.5	0.96	73	45.3
Forage sorghum	13-Jan-20	100	15055	43.5	1.09	164	39.9

Photo. 3. 14 On 18-Feb-20: Crop establishment in Rhodes grass mulch.

Seasonal change in soil water, depth of water extraction and roots.
Figure 3.12 shows soil water peaked on March 3 after which the crop removed soil water to 210 cm until maturity.

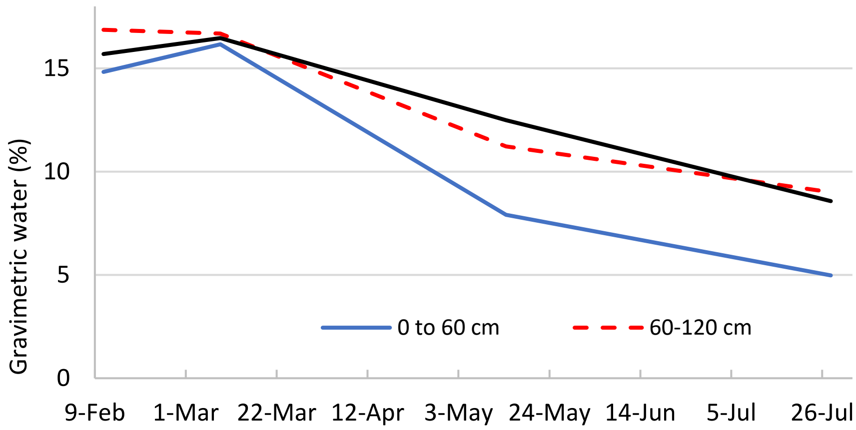

Fig 3. 12 Change in gravimetric soil water (%) with soil depth

Roots were observed to below 300 cm (maximum 340 cm) in three of the four datum areas either in the plant line or between the rows. Note finding roots using a 50 mm corer can be hit and miss so these depths are an estimate of the maximum depth. Unfortunately sampling to > 210 cm at peak soil water in March was not possible in 2020 so the volume of water extracted below this depth at picking could not be measured; it will be measured for this field in 2021.

Soil Properties: Water, Nitrate and Organic Carbon
Table 3.37 shows soil organic carbon and soil nitrate N near sowing were very low (18 kg N/ha) and typical for these soils.

Table 3. 37 Soil water nitrate and organic carbon soon after sowing.

Soil Depth Range (cm)	Gravimetric Soil Water (%)	Nitrate (mg/kg)	Organic Carbon (%)
0 to 15	15.1	4	0.50
15 to 30	13.3	6	0.29
30 to 60	16.1	6	
60 to 90	16.8	3	
90 to 120	16.9	2	
120 to 150	15.7	2	

Table 3.38 shows soil nitrate in the surface 60 cm declined to very low concentrations from sowing to 14 May. There was a very small increase in nitrate (1.4 mg/kg) between 60 and 150 cm by maturity. Soil nitrate concentrations after picking were negligible between 180 and 360 cm depth and near the lowest concentration for detection indicating deep leaching did not occur.

Table 3. 38 Seasonal change in soil Nitrate by depth

Soil Depth Range (cm)	Nitrate (mg/kg)		
	10-Feb-20	14-May-20	28-Jul-20
0 to 15	3.8	1.3	1.6
15 to 30	6.1	0.8	1.1
30 to 60	6.2	1.2	1.0
60 to 90	3.0	2.2	3.7
90 to 120	2.2	3.9	3.8
120 to 150	1.5	2.8	3.4
150 to 180			2.1
180 to 210			1.2
210 to 240			1.4
240 to 270			0.8
270 to 300			0.8
300 to 330			0.8
330 to 360			0.7

Crop Details

Table 3.39 shows, leaf area development was rapid and typical for irrigated wet season cotton, peaking 93 days after planting. Yield averaged 8.5 b/ha for the four datum areas picked. For the majority of bales produced fibre quality was basis or above.

Table 3. 39 Crop development, leaf area, boll retention, open bolls, Yield, lint %, fibre quality

Crop Development	1st square 9-Mar; 1st Flower 25-Mar Cut-out 29-Apr; 1st Open Boll 22-May 60% Open 17-Jun; 100% open 25-Jun
Final Height / node number	117 cm ± 3.4 / nodes 22 ± 0.4
Final open boll number	115 / m^2 ± 6.8
Boll retention	34.4 % ± 1.9
Maximum Leaf Area Index / date (m^2 leaf per m^2 soil surface)	4.1 ± 0.52 / 13-May
Average Yield 4 datum areas (bales / ha)	8.5 (± 0.51)
Lint %	43.1
Fibre quality	Basis or greater - except for small % Some high Micronaire and leaf trash

Key Findings Field E

- Total rainfall post planting (6-Feb) was 463mm and total Irrigation 300 mm
- Monthly rainfall compared to the long-term median (50% of years) was similar in February, well below in March and above in April.
- Forage sorghum cover had double the biomass and N as Rhodes grass; 164 vs 73 Kg N/ha, however the C:N ratio was high for both cover species and would have tied up some soil early in the season.

- At sowing soil organic carbon and soil nitrate N were very low and typical for these soils.
- Soil water peaked on March 3, despite irrigation, crop extraction of water declined to 2.1 m by maturity. Unfortunately sampling to > 2.1 m at peak soil water in March was not possible in 2020 so the volume of water extracted below this depth could not be measured.
- In soil cores taken after picking, roots were observed to below 300 cm (maximum 340 cm) in three of the four datum areas either in the plant line or between the rows.
- Soil nitrate in the surface 60 cm declined to very low concentrations from sowing to 14-May. There was a very small increase in nitrate (1.4 mg/kg) between 60 and 150 cm by maturity.
- Soil nitrate concentrations after picking were negligible between 180 and 360 cm depth and near the lowest concentration for detection; indicating deep leaching did not occur.
- Leaf area development was rapid and typical for irrigated wet season cotton, peaking 93 days after planting
- Yield averaged 8.5 b/ha for the four datum areas picked. For the majority of bales produced fibre quality was basis or above.

3.4.6 Field F - Irrigated

Methods

Table 3. 40 Field and crop details

Location /Area / Irrigation System	Tipperary / 100 ha / Pivot
Soil	Tipperary - clay loam
Previous crop	Mixed Grass
Sowing date / Variety	20 Jan 2020 / Monitoring area 1 - SC746B3F, 2 to 4 -SC748B3F
Plant population / Row width	10.9 plants / m of row. 1m row spacing

Inputs

The crop inputs provided by the grower are shown in Tables 3.41 and 3.42.

Table 3. 41 Fertiliser used

					Nutrient	Kg/ha					
Date	**Product**	**Rate kg/ha**	**N**	**P**	**K**	**S**	**Zn**	**Cu**	**Ca**	**Mn**	**B**
25/11/2019	Base	150	15	31.5		6	1.5				
14/02/2020	Blend	150	39			22.5					
20/02/2020	Blend	150	40.5	6.75	6.75	9.45	0.3	0.195	0.24	0.15	0.003
3/03/2020	Blend	150	40.5	6.75	6.75	9.45	0.3	0.195	0.24	0.15	0.003
3/04/2020	Blend	150	40.5	6.75	6.75	9.45	0.3	0.195	0.24	0.15	0.003
	Total	**580**	**124**	**28**	**44**	**37**	**0.4**	**0.2**	**16**	**0.2**	**0.2**

Table 3. 42 Chemical treatments

Date	Treatment	Chemical Product	Application Rate (L/ha)
18/02/2020	round up		
2/03/2020	Growth Reg	Pix	300 ml
24/03/2020	Growth Reg	Pix	600 ml

Measurements

The following was measured at each datum area:

Climate: Rainfall at the field. Temperature and solar radiation from automatic station 27 km SSE.

Mulch cover: Dry weight, species, N%, C%, ground cover %; from 2 m^2.

Soil Nitrate and water: To 150 cm on 15 January, 220 cm on 1 April and 16 July and 330 cm on 28 July separated into 0 to 15 cm, 15 to 30 cm depths then 30 cm increments. Sampled in plant line and between rows.

Organic Carbon %: 0 to 15 cm and 15 to 30 cm when soil nitrogen was measured

Plant measurements: Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out; Dry weight, leaf area, fruit numbers and retention from 1 m of row on 11-February, 10-March and 1 April; Crop maturity by hand picking bolls plant 3 m of row weekly from 1st open boll per till 100% open, recoding the number and weight of bolls, then calculating the date or 60% open; Lint yield handpicked from 5 m x 2 rows then 4% deducted to correct to machine picked yield; Lint% and fibre quality from grower.

Results

Climate

Rainfall and Irrigation

Rainfall is shown in Table F4, irrigation volumes were not recorded by the grower.

Table 3. 43 Growing season rainfall

date	Rain (mm)
21/01/20	65
11/02/20	24
18/02/20	70
20/02/20	50
27/2 to 1/3/20	186
9/03/20	45
16/03/20	36
10/04/20	55
Total	530

Temperature and solar radiation

Table 3. 44 Average daily solar radiation and temperature

	Solar Radiation		Temps max		Temps min	
	2019/20	LTA	2019/20	LTA	2019/20	LTA
Dec	23	22	38	35	24	24
Jan	19	21	35	34	24	24
Feb	19	21	35	34	25	24
Mar	21	23	36	34	23	23
Apr	21	22	36	35	21	21
May	18	20	33	33	15	17
Jun	20	19	33	32	12	14
Jul	20	20	33	32	10	13

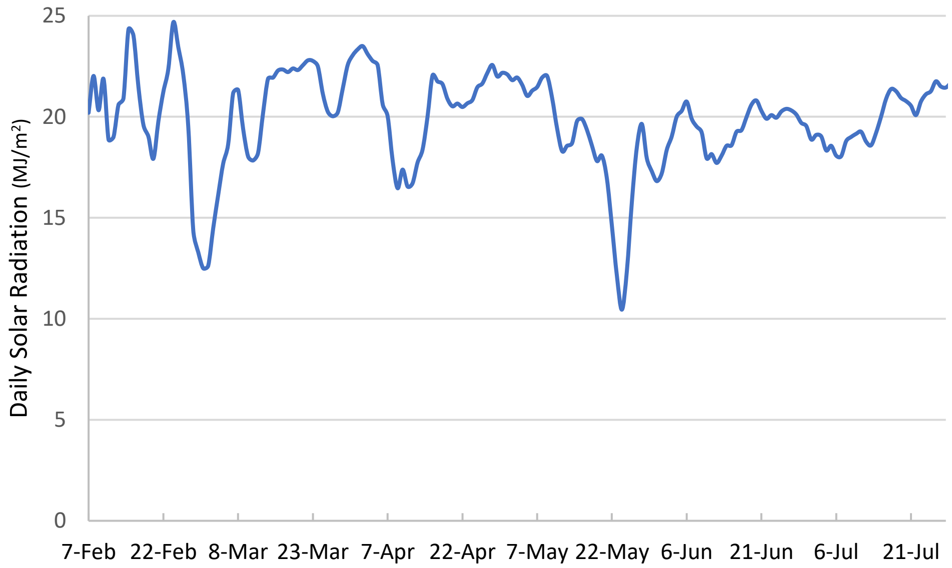

Fig 3. 13 Daily solar radiation for the growing season (shown as a 4 day moving average)

Mulch cover properties

As monitoring of this field commenced after planting, much cover was not measured and was estimated to be 100% cover, grass dominated with dry weight of 3 to 4 tone / ha (see photo)

Photo. 3. 15 Mulch cover on 5-March-2020

Soil Properties: Water, Nitrate and Organic Carbon.

Table 3.45 shows soil nitrate 31 days after planting was very low 11.2 kg N/ha and mostly in the surface 30 cm due to earlier fertiliser application and rapid crop uptake as fertiliser was mineralised to nitrate. Soil organic carbon was low compared to most soils in temperate Australia but higher than usually observed on Tippera soil in the NT.

Table 3. 45 Soil water, nitrate and organic carbon soon after sowing (24-Feb-20)

Soil Depth Range (cm)	Gravimetric Soil Water (%)	Nitrate (mg/kg)	Organic Carbon (%)
0 to 15	16	6.1	0.90
15 to 30	16	2.4	0.38
30 to 60	17	1.4	
60 to 90	17	1.1	
90 to 120	18	0.6	
120 to 150	20	0.5	

Photo. 3. 16 On 21April 2020

Table 3.46 shows by 22 April soil nitrate to 210cm was at the lowest concentration for detection. After picking soil nitrate concentrations to 300 cm remained at the lowest concentration for detection indicating deep leaching did not occur.

Table 3. 46 Seasonal change in soil Nitrate by soil depth

Soil Depth Range (cm)	Nitrate (mg/kg)		
	24-Feb-20	22-Apr-20	27-Jul-20
0 to 15	6.1	0.6	0.5
15 to 30	2.4	0.5	0.5
30 to 60	1.4	0.5	0.5
60 to 90	1.1	0.5	0.5
90 to 120	0.6	0.6	0.5
120 to 150	0.5	0.5	0.5
150 to 180		0.5	0.5
180 to 210		0.5	0.5
210 to 240			0.5
240 to 270			0.5
270 to 300			0.5

Seasonal change in soil water and depth of water extraction.

Due to rocks deeper in soil profile the maximum depth where roots were observed ranged from 126 cm to 240 cm in soil cores taken after picking. Finding roots using a 50 mm corer can be hit and miss so these depths are an estimate of the maximum depth. Unfortunately sampling to > 180 cm at peak soil water in March was not possible in 2020 so the volume of water extracted by the crop below this depth at picking could not be measured. Figure 3.14 shows soil water peaked on March 5, and despite irrigation, crop removal continued to a depth of 180 cm until picking.

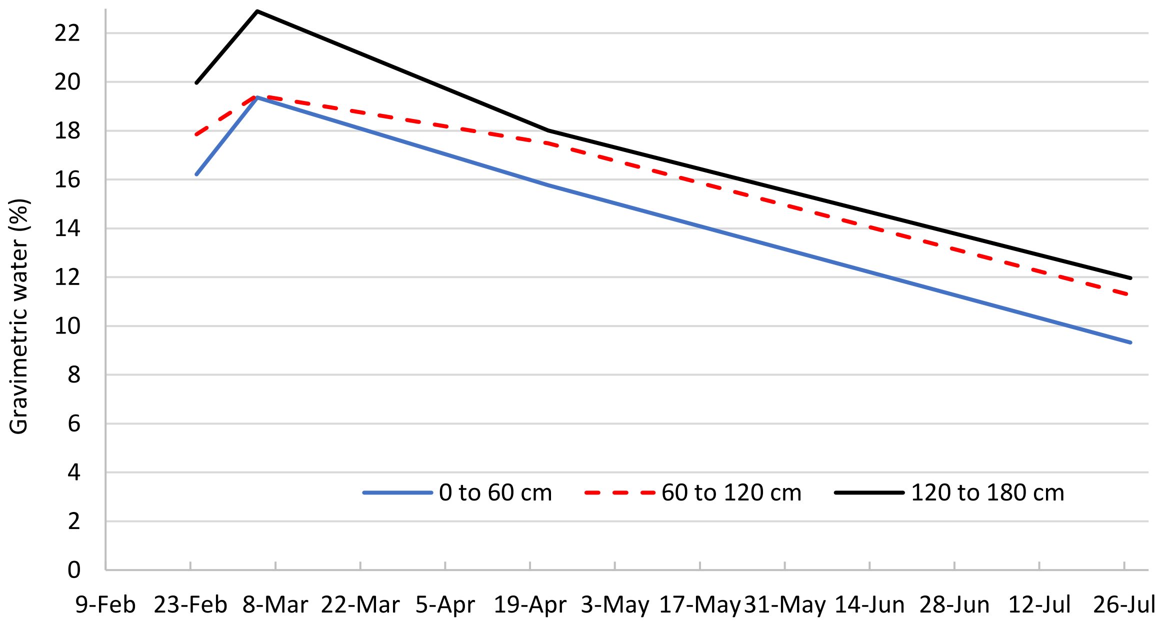

Fig 3. 14 Change in gravimetric soil water (%) with soil depth

Photo. 3. 17 Soil water sampling 5 March 2020

Crop Details

Table 3.47 shows maximum leaf area, plant height, node number and boll number were low for an irrigated crop planted mid wet season. Yield averaged 7 b/ha for the four datum areas picked and fiber quality was good (basis or above).

Table 3. 47 Crop development, leaf area, boll retention, open bolls, Yield, lint %, fibre quality

Crop Development	1st square 22-Feb; 1st Flower 14-Mar, Cut-out 7-Apr; 1st Open Boll 29-Apr 60% Open 12-May (SC748B3R) 20-May (SC746B3R); 100% open 8-Jun Defoliation 16-Jun; Picking 25-June
Final Height / node number	80 cm ± 1.9 / 20 nodes ± 0.3
Final open boll number	106 / m^2 ± 6.9
Boll retention	SC748B3F 44.1 % ± 2.0 SC746B3F 31.8 %
Maximum Leaf Area Index / date (m^2 leaf per m^2 soil surface)	2.8 ± 0.11 / 21-April
Datum area yield (bales / ha)	7.0 ± 0.33
Lint %	42
Datum area fibre quality	Basis or above

KEY FINDINGS FIELD F

- Sown 20 January 2020
- Soil organic carbon was low compared to most soils in temperate Australia but higher than usually observed on Tippera soil in the NT.
- Soil N, as nitrate, 31 days after planting was very low, 11.2 kg N/ha, and mostly in the surface 30 cm due to earlier fertiliser application and rapid crop uptake.
- After picking soil nitrate concentrations to 300 cm were at the lowest concentration for detection indicating deep leaching did not occur.
- Due to rocks deeper in soil profile, the maximum depth where roots were observed ranged from 126 cm to 240 cm in soil cores taken after picking.
- Soil water peaked on March 5, and despite irrigation, crop removal continued to a depth of 180 cm until picking.

- Sampling to > 180 cm at peak soil water in March was not possible in 2020 so the volume of water extracted by the crop below this depth at picking could not be measured.
- Maximum leaf area, plant height, node number and boll number were lowish for an irrigated crop planted mid wet season.
- Yield averaged 7 bales /ha for the four datum areas picked and fibre quality was basis or above.

Cotton Row Spacing Comparisons - 2021 and 2022

4.1 Summary

These trials were in response to grower feedback to the NT Farmers asking whether row spacing other than the traditional 1m would provide higher and more stable rain grown cotton yields. Two replicated trials with three row spacing's 0.5, 1.0 and 1.5 m (same plant density per m of row), were implemented at Douglas Daly Research Farm in 2021 and 2022, in a long term pasture field of low inherent fertility and moderate available soil water. Sowing was late in the planting window (7 & 25 January) when the likelihood of a water shortened in the growing season is greatest. Measurements focused on yield, time to maturity, soil moisture extraction and crop inputs. Due to resource limited data was collected in 2022. In the year 2021 no significant lint yield difference between row spacing was recorded within the treatments that were all averaging at 3.9 b/ha. Lint yields were significantly greater in 2022 between 0.5 m row spacing and 1.5 m that yielded 3.8 and 3.3 b/ ha respectively, while 1 m spacing recorded 3.5 b /ha. The trial with 0.5 m row spacing reached maturity between 14 – 10 days earlier than1.0 m and 1.5 m spacing in 2021 and 2022 correspondingly. However, 1.5 m spacing matured only 1 – 2 days later than 1 m. Early maturity of 0.5 m spacing was due to 75% of the yield from earlier flowering bolls on the lower fruiting branches, compared to 1.0 and 1.5 m spacing that had > 50% of yield was on the later flowering bolls. Row spacing did not affect fibre properties and there was no significant difference in the volume of soil water extraction between rows. The volume and timing of in-crop rainfall influenced the yield responses to row spacing. Until late flowering stage in 2021, the crop used above median in-crop rainfall, then accessed the available soil water until maturity this was sufficient for 0.5 m and not for delayed flowering wider rows, hence the yields. In 2022 the crop relied on soil water from 1st flower (mid-March) until at least a week after cut-out (mid-April) for all treatments and was exposed to above average temperatures, a scenario that was favourable to narrower row spacing. Conversely, above median rainfall in mid-April assisted all row spacing. Based on the seasonal conditions and the soil observed here, there was no benefit in rows wider than 1m. Yield, earliness and weed suppression advantages from 0.5 m rows are most likely in shorter growing season locations / situations, obviously these benefits need to justify stripper picking, greater planting seed and precise growth regulator management.

4.2 Background

These trials were in response to grower feedback to the "NT Farmers Association" asking whether wider rows than the traditional 1m would provide more stable rain grown cotton yields in the tropics as they do in southern growing areas. A review of cotton row spacing in mechanised tropical and subtropical Brazil and Argentina, with similar soil and reliance on in-crop rainfall to the NT, suggested narrower rows should also be evaluated for situations when the growing season is likely to be short e.g. late planting or lower rainfall areas.

Growing rain grown cotton in the tropical wet season offers many challenges, where sufficient in-crop rainfall with minimal reliance on stored soil water is critical for economically viable yields. One management option cotton growers have is to modify row configuration, which can influence crop morphology and resource use. Choosing the correct row configuration for a particular growing environment is therefore essential to maximize available resources (e.g. water) and to manage production inputs efficiently (e.g. weed control, growth regulation, fertilizer).

For acceptable yields when planted later (e.g. early January), rain grown cotton in the NT will require soil water in April and May, after the end of the wet season, to grow and finish bolls. As the local soils have low to moderate available soil water, the trial asks the question, what is the trade-off between narrow rows with more plants per hectare and fewer bolls per plant that should mature earlier, and wider rows with less plants per hectare, more bolls per plant that mature later with greater access to soil water between rows?

The aim of this study was to gain insight on how different row spacing influence crop morphology, soil water use, earliness, and yield. Results will assist developing management strategies for rain grown cotton systems in tropical northern Australia, as well as provide key parameters for calibrating/validating then applying the APSIM-OZCOT cotton simulation for regional suitability assessment.

4.3 Common Methods

Over two seasons 2021 and 2022, three row spacing's of 0.5 m, 1.0 m and 1.5 m were compared in experiments with 5 replications at Douglas Daly research Farm; sowing was in January each year and the row spacing's had with the same plant density per metre of row. Each plot was 190m long and 32 m wide.

To support growth regulator and fertiliser timing management decisions. Height, node number and Nodes Above uppermost 1st position White Flower (NAWF), weekly from 5 nodes to cut-out were measured and insects were scouted twice weekly as per standard industry practice.

4.4 2021 Trial

4.4.1 Methods 2021

Field, crop details and management inputs are provided in Tables 4.1 – 4.3.

Table 4. 1 Field and crop details

Location / Area / Cropping system	Douglas Daly / Paddock 57A - 5.2 ha / rain gown and sown zero tillage into dead surface mulch.
Soil type	Oolloo – sandy clay loam with inherently low fertility
Previous crop	Improved pasture since clearing in 1986– Brachiaria, Wynn cassia, Senna
Sowing date / Variety	7 January 2021 / SC748B3F
Plant density per m of row / per m2	7 plants per m row / 0.5 m = 14 p/m2, 1.0 m = 7 p / m2, 1.5m = 3.5 p/ m2

Table 4. 2 Fertilizer inputs and timing

Date	Product	Rate (kg/ha)	Nutrient (kg/ha)						
			N	P	K	S	Zn	Ca	B
31/12/20	Guano Sulphur Gold	130		16.4		14.3	0.5	34.1	
01/01/21	Potassium Sulphate	170			70.6	28.9			
28/01/21	Urea	140	64.4						
10/02/21	Zinc Sulphate Hepta	0.25					0.1		
16/02/21	Urea	140	64.4						
17/02/21	Etidot – 67	0.80							0.2
17/02/21	Zinc Sulphate Hepta hydtrate	0.25					0.1		
26/02/21	Etidot – 67	0.80							0.2
	Total	**582.1**	**128.8**	**16.4**	**70.6**	**43.2**	**0.7**	**34.1**	**0.4**

Table 4. 3 Chemical applications

Date	Treatment	Chemical product	Active ingredient	Application rate (l/ha)
17/12/20	Herbicide	Roundup	Glyphosate	3
07/01/21	Herbicide	Gramoxone	Paraquat	2.3
10/02/21	Insecticide	Regent	Fipronil	0.01
10/02/21	Herbicide	Weedmaster	Glyphosate	2.5
10/02/21	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.4 (0.5 m trt only)
17/02/21	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.4 (1.0 m trt only)
17/02/21	Insecticide	Regent	Fipronil	0.01
09/03/21	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.4
09/03/21	Herbicide	Weedmaster	Glyphosate	2.5
26/03/21	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.8
19/05/21	Defoliant	Promote & Escalate	Ephathon &Thidiazuron	1.5 lt & 0.15 lt
02/06/21	Defoliant	Promote & Escalate	Ephathon &Thidiazuron	1.5 lt & 0.15 lt

4.4.2 Measurements 2021

Climate: An automatic weather station located adjacent to the field recorded temperature, solar radiation and rainfall. In addition daily rainfall was recorded from three analogue rain gauges installed at two ends of the field (east, west). Rain gauges were installed on site late in December 2020 and a meteorological station late January 2021.

Pre sowing mulch cover: Dry weight, species, N%, C%, from 3 m^2 sample area per plot.

Soil nitrate, ammonia and organic carbon: Measured on 11 December 2020 to 120 cm (pre-planting), 7 April to 240 cm (cut-out) and 23 June to 350 cm (post-harvest), separated in 30 cm increments. Samples were taken in the plant-line (P) at cut-out and in the inter-row (I) at post-harvest of each plot.

Soil nitrate was measured prior to sowing, at cut-out and post-harvest. At cut-out, cores were taken in all treatments to 240 cm depth and to 350 cm depth in the 1.0 m treatment post-harvest.

Soil water: Soil water was measured regularly to capture moisture dynamics in the profile throughout the growing season. For this reason, cores were taken at 25 cm increments from the plant line from flowering. In addition, opportunistic cores after heavy rainfall events and post-harvest were taken to measure the drained upper limit (DUL) and crop lower limit (CLL) of the soil, which are needed to compute plant available water. Gravimetric soil water samples were taken on 21 January (240 cm, P), 11 February (240 cm, P), 8 March (350 cm, I), 10 March (150 cm, P+25 cm increments, rooting depth noted), 7 & 8 April (240 cm, P+25 cm increments), 4 & 5 & 6 May (240 cm, P+25 cm increments), 22 & 23 June (350 cm, P/I, rooting depth noted).
Plant measurements: Leaf area, on 10 February, 3 March, 17 March, 30 March and 14 April, 2021. Crop maturity and final open boll number; by weekly hand picking bolls from 3 m of row commencing 1st open boll per till 100% open, recording the number and weight of bolls, then calculating the date of 60% open. Lint yield hand-picked from 20 m^2 for the 0.5 and 1.0 m treatments and 15 m^2 for the 1.5 m^2 treatment, then 4% deducted to correct to machine picked yield. A 300g sample of seed cotton was sent to CSIRO at Narrabri NSW for fibre quality testing (HVI) and ginning. After hand picking the remainder of the field was machine picked (great majority) by a round bale 6 row picker, and the field average for lint % and fibre qualty used to adust small plot data to commecial scale. Yield mapping from 2 m row at the time of hand-picking.

4.4.3 Results 2021

Climate: Table 4.4 shows rainfall near the long term median (LTMd) for January and 50 mm above the LTMd for February and March. While rainfall in April was in the bottom 10%. Total growing season rainfall = 706 mm. Total post 1st flower rainfall = 213 mm

Table 4. 4 Monthly rainfall volumes collected at the site; the rain gauge average is shown

Month	Observed (mm)	LTMd (mm)
January	273	255
February	290	243
March	212	158
April	1	21
May	0	0
Total	**776**	**677**

Figure 4.1 shows the within season rainfall variability, with regular rainfall events during reproductive development, first square to cut-out (9 Feb to late March). Rainfall in the second half of March (16th to 31st) was double the long term median and would have minimised water stress in late flowering.

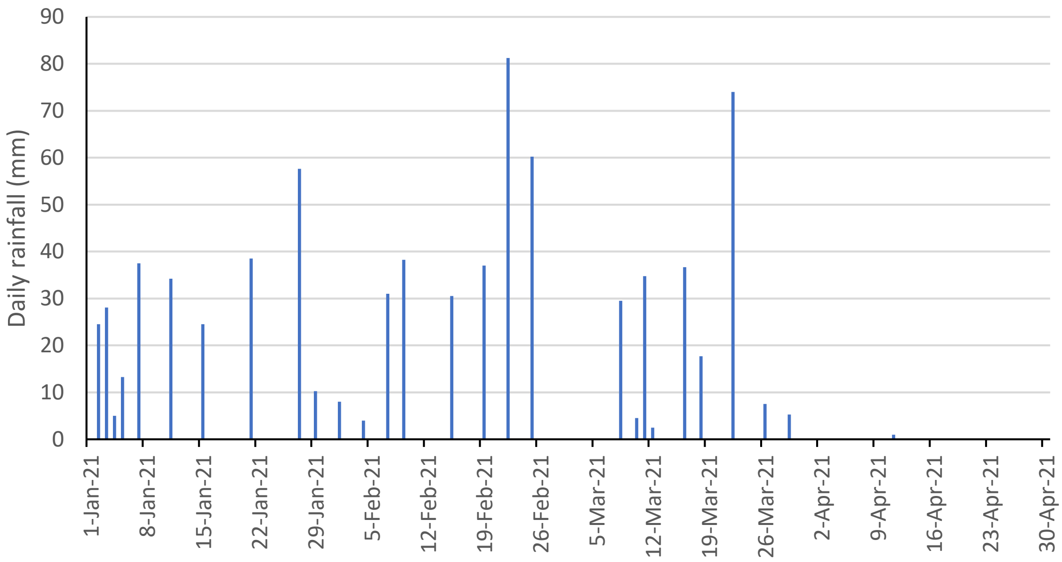

Fig. 4. 1 Daily rainfall volumes measured with the meteorological station at the trial site.

Average maximum and minimum temperatures did not deviate much from the long-term median, with only unusually cold night temperatures recorded in May (Table 5). Due to cloud cover solar radiation was 10 to 20% less than average January to April.

Table 4. 5 Growing season monthly average daily solar radiation and temperature compared to long term average (LTA) or median (LTMd)

Month	**Solar Radiation(MJ/m^2)**		**Temps max (C^o)**		**Temps min (C^o)**	
	2021	**LTA**	**2021**	**LTMd**	**2021**	**LTMd**
Jan	18	21	34.4	33.7	24.3	23.9
Feb	17	21	34.3	33.5	23.8	23.7
Mar	20	23	35.4	34.0	23.0	23.2
Apr	20	22	36.1	34.7	18.0	20.5
May	20	20	34.6	33.3	11.9	16.7

Pre sowing mulch cover properties:

Table 4.6 shows the mulch cover properties at the trial site prior to sowing. About 100kg/ha of N was contained in the soil cover with the green mulch containing 66 kg N /ha and a more favourable ratio C:N due to the legume (Wynn cassia). Less nitrogen was contained dead mulch due to a higher C:N ratio, hence a slower mineralisation rate.

Table 4. 6 Mulch cover properties

Cover	**Date sampled**	**Dry weight**	**Carbon**	**N**	**N**	**C:N**
		kg/ha (se)	**%**	**%**	**kg/ha**	
Live (Brachiaria spp., Wynn cassia, Senna)	14 Dec 20	4450 (319)	43.7	1.49	66	29.3
Dead (mainly grass)	14 Dec 20	3215 (470)	43.8	1.09	35	40.2

Photo. 4. 1 Cover 5 days prior to planting (2 January 2021).

Photo. 4. 2 Left: planting into killed mulch (7/1/21), Right: establishment of 50 cm spacing (15/1/21)

Soil chemical properties and soil water

Table 4.7 shows soil nitrate, ammonium, and organic carbon approximately 4 weeks prior to sowing. All were very low, indicating crop N availability from these sources would be insufficient for economically viable yields.

Table 4. 7 Soil chemical properties prior sowing (11 December 2020)

Soil depth (cm)	Nitrate (NO_3^-) (mg/kg)	Ammonium (NH_4^+) (mg/kg)	Organic carbon (%)
0-30	< 1	< 1	0.33
30-60	< 1	< 1	0.21
60-90	< 1	< 1	0.12
90-120	< 1	< 1	0.14
120-150			
150-180			
180-210			
210-240			

Table 4.8 Shows Soil nitrate was moderately increased at cut-out due to the decomposition of mulch and the application of urea N. For all treatments modest to low concentrations of nitrate accumulated where the clay content increased, about 60 cm, continuing to 180 cm depth for all treatments. Between 240 and 350 cm depth, soil nitrate was negligible low indicating deep leaching did not occur.

Table 4. 8 Seasonal change in soil nitrate (mg/kg) by depth

Soil Depth (cm)	7 Apr 21 (cut-out)			23 Jun 21 (post-harvest)
	0.5 m	**1.0 m**	**1.5 m**	**1.0 m**
0-30	< 1	< 1	< 1	1.3
30-60	< 1	< 1	1.4	1.0
60-90	4.2	3.8	5.2	4.0
90-120	7.4	5.2	4.8	6.8
120-150	5.2	4.6	4.6	6.3
150-180	3.2	3.2	2.6	4.5
180-210	< 1	2.0	1.4	3.0
210-240	< 1	1.2	1.0	1.4
240-270				< 1
270-300				< 1
300-330				< 1
330-350				< 1

There was no difference in total nitrate throughout the soil profile between the treatments, suggesting similar rates of crop uptake.

Change in soil water and depth of extraction:

Figure 4.2 shows the change in gravimetric soil water (%) by depth throughout the growing season for 0.5, 1.0 and 1.5 m row. There was no significant difference in soil water extraction between row spacing at any sampling date or depth increment. As expected, soil water was largest at the start of the growing season when in-crop rainfall was greatest then declined to maturity as daily rainfall volumes decreased. The crop relied on soil water from late March when the wet season terminated. By late April available soil water was extracted to 150 cm then continued in the 150-240 cm layer (the maximum depth that could be sampled without the DEPWS deep coring rig). Sampling one month after picking with the DEPWS rig found the presence of roots at 300 cm for all treatments, indicating water extraction to this depth. However some of this deep soil water may not have contributed to yield as leaf growth post physiological maturity relied on this water. A greater proportion soil water was stored in the 60-150 and 150-240 layers, which have the largest clay content.

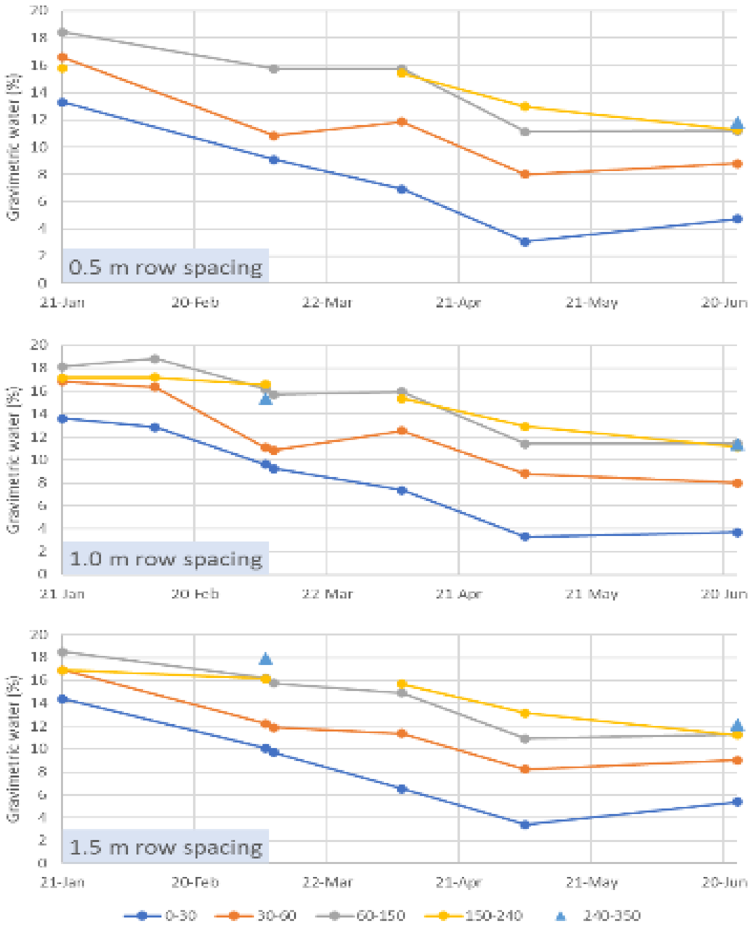

Fig. 4. 2 Seasonal change in gravimetric soil water (%) with soil depth (cm) for 0.5, 1.0 and 1.5 m row spacing.

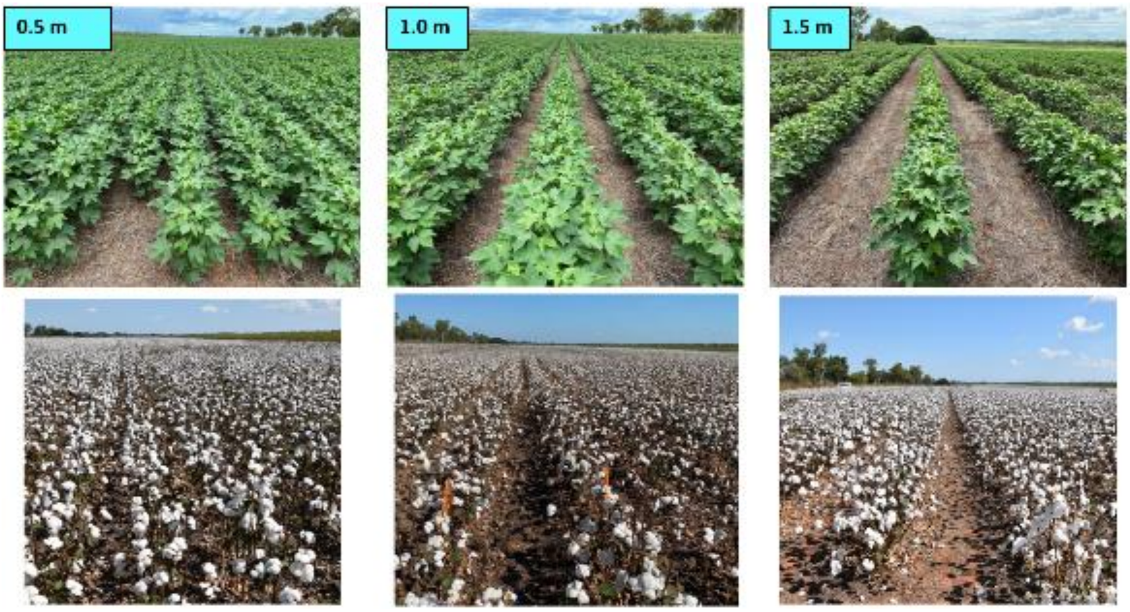

Photo. 4. 3 Above - canopy development on 21 February 2021 (45 days after sowing); below - at picking, June 2021

Yield, crop maturity and development:

The 2021 season produced no significant yield difference between row spacing, the treatments averaging 3.9 b/ha ($lsd_{0.05}$ 0.42), although there was a greater range of plot yields for the 0.5 m spacing.

The 0.5m spacing reached maturity 14 days earlier than the 1m and 1.5 m spacing (Table 4.9). The earlier maturity of the 0.5 m row spacing was due to 75% of the yield being grown on earlier flowering bolls on the lower fruiting branches from first position bolls (1-4 P1, 5-8 P1), compared to 1.0 and 1.5 m row spacing where yield was mainly (>50%) on later flowering vegetative branches (VB) and upper fruiting branches (5-8 P2 and > FB 9 to 13), (Figure 4.3). Boll retention was highest for the 1.5 m treatment (55%), suggesting less shading of lower leaves and competition for resources due to longer flowering and boll filling period compared with the other treatments (Table 4.9). There was no effect of row spacing on fibre properties, which were at least “Basis’ (no discount). However machine picking of the 0.5 m spacing would require a striper front which can increase the trash content of the lint. Leaf area peaked 82 days after planting being greatest and fastest in the 0.5 m spacing (Table 4.9 & plates). A benefit of the faster canopy closure by the 0.5m spacing the requirement for 1 in-crop treatment for weed control (glyphosate) compared with 2 for wider rows (Table 4.3).

Table 4. 9 Crop development dates, maximum leaf area Index (LAI), boll retention, open bolls, yield, lint %, fibre quality. Standard error is in brackets.

Treatment		**0.5 m**	**1.0 m**	**1.5 m**
Crop development	1st square	9 Feb	9 Feb	9 Feb
	1st flower	3 Mar	3 Mar	3 Mar
	Cut-out	22 Mar	22 Mar	29 Mar
	1st open boll	21 Apr	21 Apr	21 Apr
	60% open boll	6 May	20 May	21 May
	Picking	2 Jun	2 Jun	2 Jun
Final height / node number		87 (2.1) / 20 (0.2)	102 (1.7) / 20 (0.3)	118 (1.6) / 22 (0.2)
Final open boll number / m^2		71 (4.5)	54 (4.3)	62 (2.3)
Average boll weight (g)		4.1 (0.13)	4.3 (0.11)	4.3 (0.08)
Max. LAI / date		3.8 (0.36) / 30 Mar	3.3 (0.24) / 30 Mar	3.2 (0.20) / 30 Mar

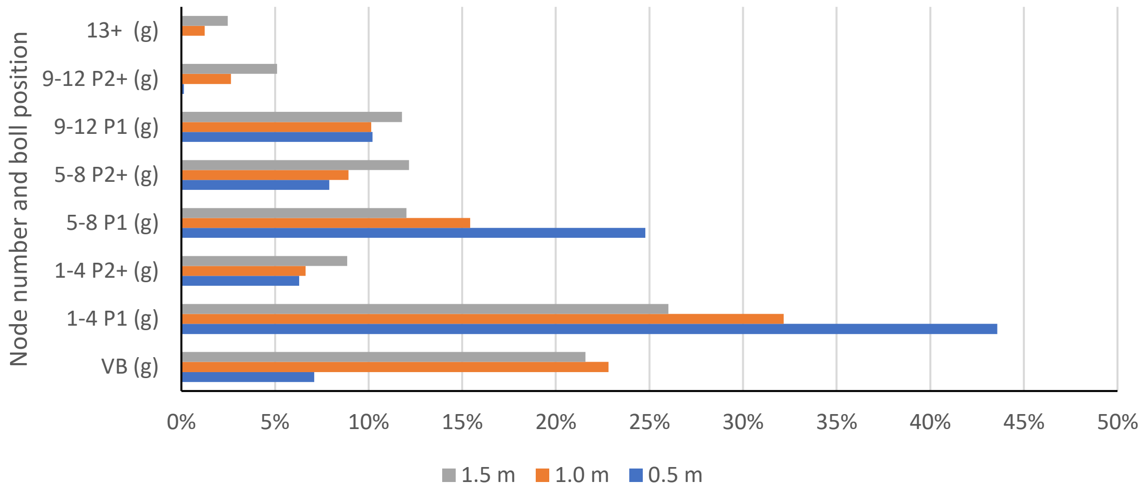

Fig. 4. 3 Within plant Yield distribution (% of total) of the 0.5, 1.0 and 1.5 m row spacing.

4.5 2022 Trial

4.5.1 Methods 2022

As per 2021, 3 row spacings of 0.5 m, 1.0 m and 1.5 m, all with the same plant density per metre of row were compared in an experiment with 5 replications, in a randomised complete block design. The experiment located in the same field as 2021 (57A) and was sown zero till with treatments established into the same plots 2021.

Photo. 4. 4 Left: October 2021 after cotton Centre: 14/12/21 self-sown Sabi grass, Right: 06/01/22 dead cover with previous cotton stalks.

4.5.2 Measurements 2022

Being in the final year of the project and the NTDITT contracted commitment to cotton R&D was reduced to crop establishment evaluations. CSIRO, supported by the planned CRDC in-kind, committed to undertake repeat of the 2021 experiment in 2022 with reductions in measurements, (mainly related cotton model validation), while maintaining measurements essential to agronomic comparison. Unfortunately a dire shortage of available casual labour after planting (4 people were offered contracts then found other work after commencement) necessitated further scaling back of measurement. The DDRF farm staff ensured the crop was well managed. The measurements taken are listed below.

Climate: As per 2021

Pre sowing mulch cover: Percentage, and species by visual observation prior to killing.

Plant measurements: Established plant population per m of row on 8/2/22**.** Date of 1st square, 1st flower, cut-out, 1st open boll, 60% open boll from in field boll counts. Final open boll number, 1m of row on 31/5/21. Lint yield hand-picked from 10 m^2 for the 0.5 and 1.0 m treatments and 15 m^2 for the 1.5 m^2 treatment on 8/6/22.

Management details

Previous crop and cotton establishment: Cotton stalks from 2021 were slashed after picking in June 2021 then allowed to regrow in early wet season rains and selectively killed with Starane herbicide on 09/12/21, self-sown Sabi grass (*Brachiaria spp.*) provided much cover to sow into (see plates), visually assed as 100% with dry weight of 2.5 to 3 t/ha (Table 4.10).

- **Sown:** 25 January 2022, after 2 failed plantings on due to planter breakdown on January 10 & 17.
- **Plant population:** established 8.2 plants per linear metre of row in each treatment.
- **Variety:** SC714B3F
- **Fertiliser:** 17/12/21 450 kg/ha of N: P: K: S 15_5_14_14 + 0.01 Zn and 0.02 B, Urea 07/02/22 & 13/03/22 @ 100 kg/ha & 150 kg/ha. Total nutrient applied per ha: N 169 kg, P 22.5 kg, K 63 kg, S 63 kg, Zn 0.5 kg, B 1 kg.
- **Picking:** 08 /6/22

Table 4. 10 Chemical treatments

Date	Treatment	Chemical product	Active ingredient	Application rate (/ha)
09/12/21	Herbicide	Starane + Uptake	“	1.2 kg + 0.5 lt
24/12/21	Herbicide	Panzer 450 + Uptake	Glyphosate	3 lt
24/12/21	Insecticide	Chlopyrifos + SP700	“	0.75 lt
26/01/22	Herbicide	Gramoxone	Paraquat	2.3 lt
08/03/22	Herbicide	Panzer 450 + Uptake	Glyphosate	1.9 lt
10/03/22	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.4 (0.5 m trt only)
25/03/22	Growth regulator	Mepiquat 350	Meqiquat Chloride	0.4 (1.0 & 1.5 m trts)
27/04/22	Insecticide	Albatross	Fripronil	65 ml
27/05/22	Defoliant	Promote + Escalate	Ethephon + Thidiazuron + oil	1.5 lt, 0.15 lt, 0.5 lt



Photo. 4. 5 January 2022, Left: Sowing, Centre and Right: crop establishment and past cotton stalks

4.5.3 Results

Climate

Table 4.11 and Figure 4.4 show maximum temperatures March to May were 2 to 3 degrees above the long term median. Solar radiation was near the LTA. Only January exceeded the median rainfall. The period from February 21 to April 12 was dry, a larger than median rainfall event in mid-April was very timely for this late planted crop. Total growing season rainfall = 421 mm. Total post 1st flower rainfall = 71.5 mm.

Table 4. 11 Growing season monthly average daily solar radiation, temperature and rainfall compared to long term average (LTA) or median (LTMd).

Month	Solar Radiation (MJ/m^2)		Tmax (C^o)		Tmin (C^o)		Rainfall (mm)	
	2022	LTA	2022	LTMd	2022	LTMd	2021/22	LTMd
Jan	19	21	35.0	33.7	24.1	23.9	288	255
Feb	20	21	34.9	33.5	23.9	23.7	193	243
Mar	22	23	36.7	34.0	23.5	23.2	82	158
Apr	21	22	37.0	34.7	20.8	20.5	65	21
May	19	20	35.7	33.3	17.1	16.7	0	0

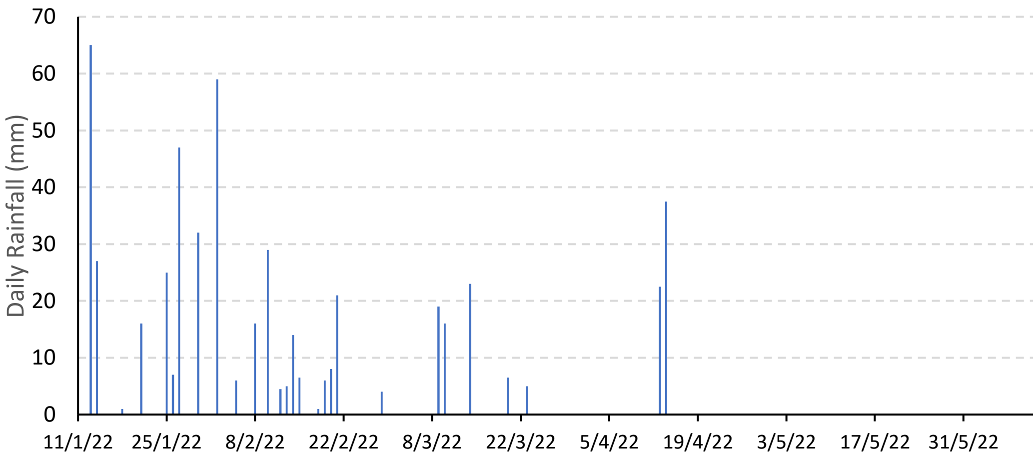

Fig. 4. 4 Growing season daily rainfall. NB planting was on January 25, 2022

Photo. 4. 6 March 7, 2022: canopy development at early squaring

Photo. 4. 7 April 12, 2022: water stress symptoms post cut-out in all row spacing

Crop development:

Table 4.12 shows, the flowering period, (time from 1st lower to cut-out), was longer for 0.5m row, which in 2022 reflected differences in time to maturity. The 0.5 m spacing reached maturity 10 days earlier than the 1.0 m, the 1.5m spacing matured only 2 days later than 1m. Otherwise there was no differences between row spacings in time to crop development or final boll number. The only significant differences where the 0.5m row spacing was earlier for time to cut-out and maturity

Table 4. 12 Development dates and final boll number.

Measurement	**Row Spacing**		
	0.5 m	**1.0 m**	**1.5 m**
1st square	3-Mar	3-Mar	3-Mar
1st flower	15-Mar	15-Mar	15-Mar
Cut-out	26-Mar	6-Apr	8-Apr
1st open boll	2-May	2-May	2-May
Maturity (60% open boll)	15-May	25-May	27-May
Final open boll Number / m^2	64	70	67

Photo. 4. 8 June 8, 2022: Picking

Yield:

Figure 4.5 shows, lint yields in 2022 were significantly greater for 0.5 m row spacing than 1.5 m, 3.8 vs 3.3 b/ ha, the 1 m spacing being intermediate, 3.5 b /ha, but not significantly less than 0.5 m.

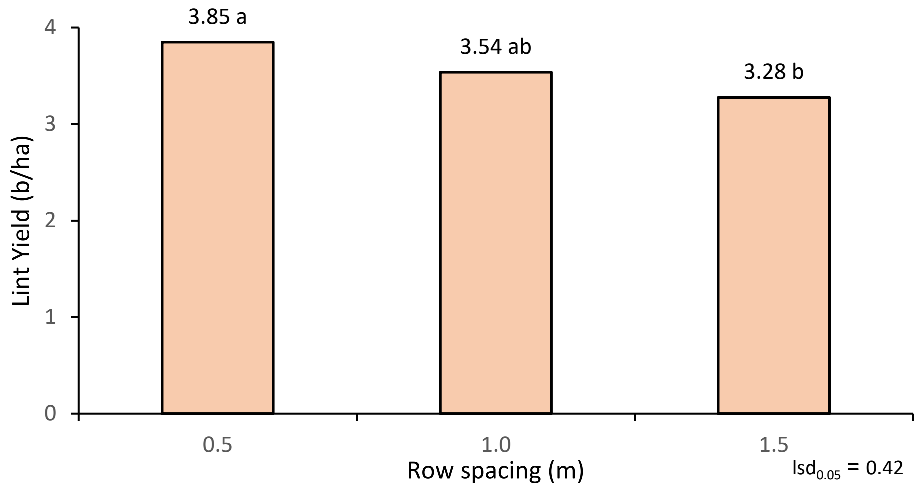

Fig. 4. 5 Yield 2022, means with the same letter are not significantly different.

5. Maximising Cotton Seedling Establishment

5.1 Summary

Good seedling emergence and establishment in cotton is an important factor because it determines seedling vigour, plant population and eventually better yields. However, due to a number of factors including course soil texture, high soil temperatures, soil crusting, placement of seed in the planting furrow, seedling disease and moisture availability NT farmers have been reporting poor cotton establishment with consequences of replanting outside the optimum planting window or having a patchy crop establishment. The most practical solution to some of these problems is having the right machinery configuration for seed placement and improving soil cover to conserve the moisture. In this research we investigate planter configurations and soil mulch cover options that can improve the reliability of cotton seedling establishment and survival in the NT. Five planters configurations were evaluated (coulters x press wheels) for their capability to place cotton seed into soil moisture at 3 to 4 cm below a surface mulch and with minimal disturbance of the mulch to protect seed from high soil temperatures and soil crusting because compaction from intense rainfall. Two mulch scenarios were compared in the research, green recently sprayed and dead mulch. All planter configurations placed most seed at the desired depth, ensured much cover was not displaced to protect the seed. Although soil temperatures at seed depth did exceed 40 ^{0}C on hottest days. There was a low percentage of seed pinning into mulch in the conditions observed here when planting was done in thick wet mulch cover. The interaction between mulch cover management and weather proved challenging. Death of > 50% of seedlings occurred in all planter configurations after sowing into green mulch and dead. This may be due heavy rain that levelled the mulch exposing the previously shaded seedlings to extremely hot humid conditions. The rain grown cotton yields were reflected by the in-crop rainfall after flowering, where even though we had 50% of seedling death, larger branching cotton plants compensated and a good yields were recorded (5.7 b/ha). Future cotton establishment work needs to be done to evaluate more mulch cover, planter set up, climate and soil scenarios. Also, there is need to find out how much is Cotton Seed viability affected when being exposed to varying conditions while on freighted. Further Investigation is required into soil conditions including diseases and pests.

5.2 Background

Poor cotton establishment on course textured soils in the NT has been a key issue over the past two seasons for commercial on-farm testing of cotton that is planted early in the wet season. The consequences are replanting outside the optimum planting window or patchy crop establishment; both with yield penalties. Poor establishment is caused by a combination of high soil temperatures, soil crusting, seed placement in the planting furrow (Particularly when planting into thick mulch cover), seedling disease, and moisture availability. Optimal machinery configuration is likely to improve seedling establishment in cotton.

Objective

To investigate planter configurations and soil mulch cover options to improve the reliability of cotton seedling establishment and survival in the NT.

Trial location and site description

The research trial was contacted at Douglas Daly Research Farm (DDRF) that is located 230 km south of Darwin, 220 km north-west of Katherine, at 13^{o}50’S, 131^{o}10’E and approximately 51 meters above sea level (asl). The research station farm boarder’s the Daly and Douglas rivers to the south and north–west side respectively and it’s topography is relatively flat having mostly sandy red earths (Blain soil type 4C, 4B1, 4A2) and loamy to heavier red earths (Oolloo and Tippera) soil types.. Climatic conditions at DDRF is characterised by tropical Annual rainfall of about 1207 mm that is distributed in two seasons of rainfall in 7 months and little or no in rain the other 5. Generally the location of the farm has varied temperatures ranging from mean minimum of between 13 to 24^{o}C and maximum 31 to 37^{o}C monthly.

5.3 Materials and Methods

Two experiments on Oolloo soil type at Douglas Daly Research Farm). Experiment 1 (E1) was sown December 18th into green mulch and the 2^{nd} experiment (E2) sown January 6th into dead mulch. The planter used was a John Deere Maxi-Merge 2 row precision planter which was set to plant 11 seeds per meter for the trial area. The cotton variety used was SC748B3F.

5.3.1 Treatments

Five planter configurations in 4 replications were compared – All sown with double disc opener provided by Vanderfield (see pics).

1. No coulters, Rubber press wheels,
2. 40cm Bubble coulter + Rubber closing press wheels
3. 40cm Fluted coulter +Rubber closing press wheels
4. 40cm Fluted coulter + spiked press wheels
5. 40cm Bubble Coulter + spiked press wheels

Photo. 5. 1 Left- Bubble coulters and Right - Fluted coulter

Photo. 5. 2 Left - Spiked press wheels and Right - Rubber press wheel

Photo. 5. 3 Stephan Frahm from Vanderfield-RDO, above left, supplied a two row planter with various planter configuration's, monitoring sensors and assisted with planting set up, changing with a number of different coulters and press wheels. Seen here with planter set up.

5.3.2 Measurements

Weather data (daily min and maximum temperatures, light intensity, and cumulative rainfall) recoded by an automatic station in the field and supported by the official BOM station 3 km W. Two manual rain gauges were located either end of the field the site.

Pre-season mulch weight and cover estimates: Pre-planting mulch weights and cover estimates were recorded. After planting, seed depth, seed spacing and placement was recorded in each treatment.

At planting soil samples were collected from the plant line in each plot at seed depth to ascertain soil moisture. After planting seed depth, seed spacing, and placement was recorded in each treatment.

Soil temperature loggers were installed in the planting rows of each treatment to the depth of the seed.

Plant emergence, establishment and mortality: The Number of established plants per plot (2 x 2 m of row) was recorded every 5 to 6 days from planting date until the 21 January 2022.

Crop monitoring from establishment to defoliation, twice per week for insect and disease scouting and weekly crop height / node number for growth management). Hand-picked yields were taken from 4m of row and 4% deducted to correct to machine picked yield.

5.4 Results

5.4.1 Climate

Table 5.1 and Figure 5.1 shows rainfall was above on near the long term median (LTMd) for December and January. The period from February 21 to March was dry, a larger than median rainfall event in mid-April was very timely for the later planted second trial. Maximum temperatures March to May were 2 to 3 degrees above the long term median. Solar radiation was near the LTA and the total growing season rainfall E1 = 824 mm, E2 = 562

Table 5. 1 Growing season monthly average daily solar radiation, temperature and rainfall compared to long term average (LTA) or long term median (LTMd).

Month	Solar Radiation (MJ/m^2)		Temps max (C^o)		Temps min (C^o)		Rainfall (mm)	
	2022	LTA	2022	LTMd	2022	LTMd	2022	LTMd
Dec	19	22	34.9	35.0	23.6	23.8	312	190
Jan	19	21	35.0	33.7	24.1	23.9	288	255
Feb	20	21	34.9	33.5	23.9	23.7	193	243
Mar	22	23	36.7	34.0	23.5	23.2	82	158
Apr	21	22	37.0	34.7	20.8	20.5	65	21
May	19	20	35.7	33.3	17.1	16.7	0	0
Jun	17	19	34.0	31.4	15.5	13.7	0	0

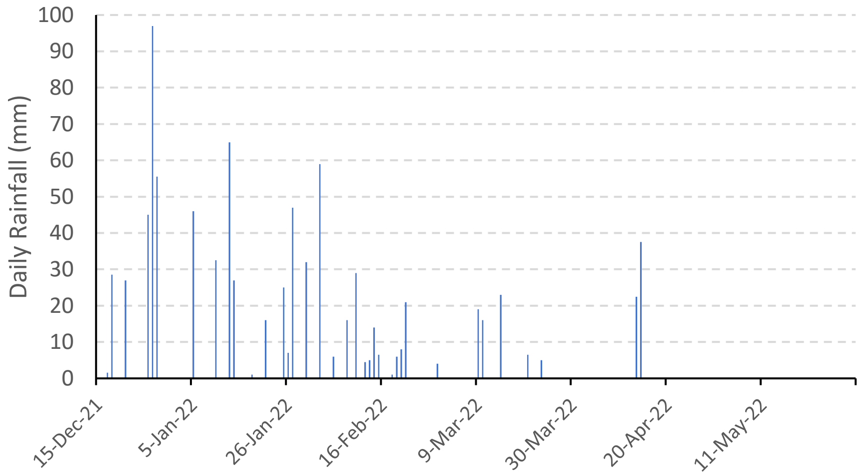

Fig. 5. 1 Daily rainfall volumes at the trial site

5.4.2 Mulch Cover

Table 5.2 shows the mulch cover properties for each trial prior to sowing. All cover was generated from self-sown pasture seed produced in the previous wet season, then established and grown or rainfall prior to planting.

Pre-planting treatments

The field that was used for this trial was previous used for pigeon growing as a trap crop and prior to that, it was under pasture grass and legume species mainly; (Sabi grass, , Urochloa mosambicensis, Summer grasses Digitaria and Bracharia spp and wynn cassia Chamaecrista rotundifolia) for cattle grazing. Prior to planting, mulch weight and cover estimation were recorded to be 3 – 4 t/ha at 100% soil cover and fertilizers applied to the soil surface using a fertilizer spreader.

Table 5. 2 Much cover dry weights and species composition

Trial	Cover	Date sampled	Dry weight kg/ha
E1	Green mulchMainly grasses	17 Dec 21	3781
E2	*Dead (mainly grasses)*	05-Jan-22	4255

Photo. 5. 4 Measuring self-sown pasture cover prior to planting E1.

Photo. 5. 5 E2 showing dead mulch at crop establishment

5.4.3 Seedling Survival

Figure 5.2 shows the E1 trial on 23-Dec-21, 5 days after sowing (DAS) seedling establishment met the target of 8 / m2 for all planter configurations with no statistical difference between planter configurations. Death of seedlings between 5 and 11 DAS reduced the average plant density to 4.8 / m^2, being patchy within and between the plots.

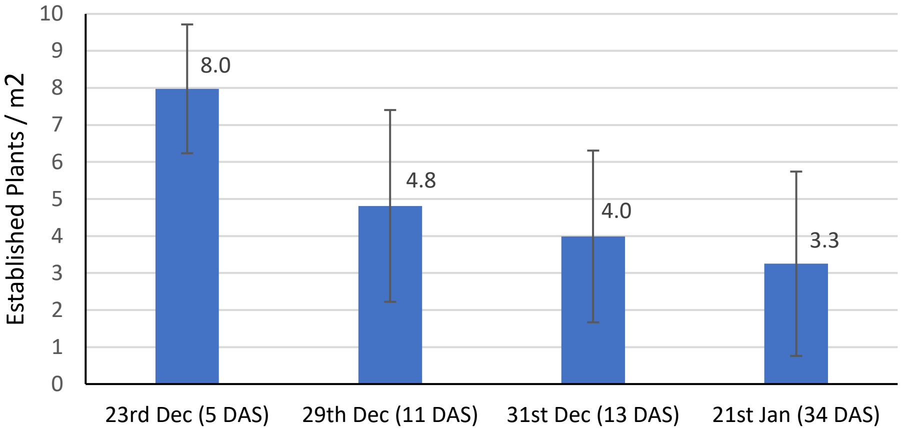

Fig. 5. 2 The change in the number of surviving seedlings for the E1 trial from 23-Dec-21, 5 days after sowing (DAS) to 21-Jan-22.

There was no significant difference between planters configurations, Bars are ± $lsd_{0.05}$ for each measurement date. The later planted E2 trial plant establishment was even and near the target density of 8 plants / m^2 there was no death of seedlings 6 and 11 days after sowing. There was no significant difference between planter configurations.

Photo. 5. 6 The second trial, E2, 09/02/22

5.4.4 Plant line soil water

Soil water at the seed depth was high at planting of both trials (Table 5.3) being similar to the drained upper limit for this field as measured for APSIM model soil characterisation (see row spacing report). Soil water at establishment of E1 was also acceptable and well above the crop lower limit of 4% measured for this field.

Table 5. 3 Gravimetric soil water to the depth of seed (~ 4 cm) at planting for trials E1 and E2 and at establishment for E1 (23/12/21).

Planter Configuration	Gravimetric Soil Water (%)		
	E1 18/12/21	E1 23/12/21	E2 06/01/22
No coulters, Rubber press wheels	16	12	14
Bubble coulter + Rubber closing press wheels	14	13	14
Fluted coulter +Rubber closing press wheels	16	14	15
Fluted coulter + spiked press wheels	15	12	15
Bubble Coulter + spiked press wheels	16	13	14
$Lsd_{0.05}$	1.38	ns	ns

5.4.5 Soil temperatures at seed depth

Trial E1

Due to the heavy mulch cover only small differences in soil temperatures at seed depth were measured between planter configurations. Figure 5.3 shows daily maximum soil temperatures were at or above 40Cº for 5 of the first 6 days after planting and never less than 37.5 Cº. However, plant establishment was at the target 8 per m of row 5 days after sowing on the 23 December (Table 5.3)

It is not clear why about 50% of seedlings perished between December 23 and 29 (Table 5.3) despite 3 days of cooler wet weather (Figure 5.3). It is possible the dying mulch intially protected seedlings from direct sun light and high air temperatures and after the rain leveled the mulch the unhardend seedlings were damaged.

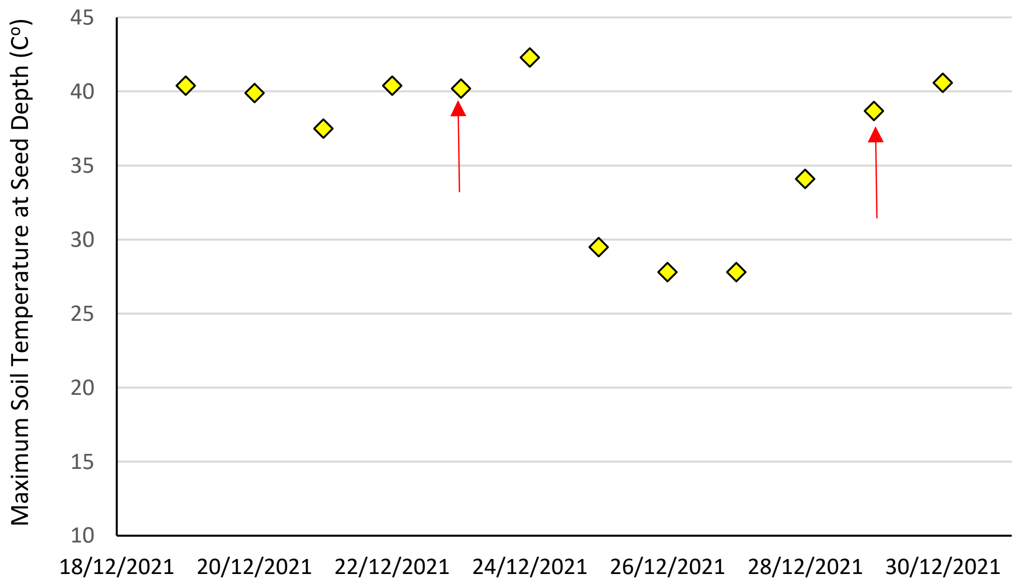

Fig. 5. 3 The daily maximum soil temperature at seed depth (~4cm) from 19/12/21 (1 day post planting) until 30/12/21. Arrows show the days when plant establishment was counted.

Trial E2

Extreme soil temperatures at seed depth were not observed over the 6 days following sowing; only reaching a maximum of 38 Cº briefly on 6/1/22 otherwise daily maximum soil temperatures were between 31 and 34 Cº.

5.4.6 Yield and plant population at picking

Table 5.4 shows trial yields and final plant populations. While there were no yield differences between planter configurations, the good yield of earlier sown E1 trial despite a low plant population, demonstrated the compensation capacity of cotton when there is sufficient rainfall and growing season length. The lower yield of E2 reflects the later planting and below median rainfall during flowering in March (Figure 5.1).

Table 5. 4 Average trial seed cotton, lint yield and plant number / m2 (standard error) for the establishment trials.

Trial	Seed Cotton (kg/ha)	Lint Yield (b/ha)	Plant No. (m^2)
E1	3302 (218)	5.73 (0.38)	4.6 (1.9)
E2	2762 (192)	4.79 (0.34)	7.5 (1.0)

Photo. 5. 7 Trial E1 produced good yields despite a low and variable plant population (average 4.6 pl / m2). A long growing season, due to a mid-December planting, combined with above average in the first 60 days produced large branchy plants with many bolls. Handpicked yields were taken in all treatments prior to being machine picked.

Photo. 5. 8 E2 despite having an even target plant population of 8 pl/m2, yield about 1 b/ha less than E1 due to later planting, 6 January, receiving significantly less rainfall during flowering and boll growth.

Photo. 5. 9 After planting: Seed depth and placement recordings were taken and soil temp loggers were installed in each treatment.

5.5 Observations and Comments

- At planting grass pinning was a problem, mainly in the green mulch, however there was no real differences in pinning between the cutting bubble coulter and the wave coulter. Pinning was more conducive to the mulch density. When pinning was occurring, it caused variation in seed soil contact and seed planting depth.
- At planting the soil moisture was observed to be good. Gravimetric water around 15%--50mm of rainfall fell prior to planting.
- The first planting was done into standing green mulch. After planting the mulch fell over the rows due to a storm event. This then caused a problem for young seedlings trying to grow through collapsed mulch cover. In these areas the indicial plant establishment was even, but after 12 days, with rain and mulch collapsing over rows, coinciding with hot conditions, plant numbers fell away as data show.

- The early emergent counts taken in each planting were very similar @ 8 plants/metre.
- Data loggers were installed in planting rows. Soil temperature when plants emerged was around 27- 36.
- Further investigation needs to be done in cotton establishment work to evaluate more mulch cover x planter set up x climate/soil scenarios.
- How much is Cotton Seed viability affected when being exposed to varying conditions while being freighted.
- Investigation is required into soil conditions/diseases, pathogens (e.g. Macrophomina).

6. Implementing Northern Territory Locations into the CropARM Decision Support Tool

6.1 Summary

Availability of soils suitable for crop production and access to significant water resources has made The Northern Territory of Australia an attractive option for the development of an irrigated broad acre cropping sector. Contrary to that, the Territory has historically been dominated by low input pastoral/rangeland agriculture. To develop a cropping enterprise in NT will require the development of experience and understanding of crop growth. Crop modelling can be used to simulate cropping scenarios and yield potential over long time frames in a matter of minutes and facilitate a rapid development of the necessary experience and knowledge. Therefore in this research we aimed at adding locations from the northern territory to the CropARM tools that provide coverage for crops of maize, sorghum, soybean, mungbean, peanuts and chickpeas. The outcome of this will give NT farmers and other agricultural decision makers the ability to quickly access and easily analysis cropping scenarios for irrigated and dryland production on a range of cereal and grain legume crops. The result of the analysis will be used by new participants in making appropriate cropping decisions by analysing crop management scenarios and help NT farmers to establish broadacre cropping.

6.2 Introduction

The Northern Territory of Australia has long been an attractive option for the development of an irrigated broad acre cropping sector (Chapman et al. 1996). This is due to the availability of soils suitable for crop production (Wilson et al. 2009) and access to significant water resources (Cresswell et al. 2009; CSIRO 2009). The development of cropping enterprises in areas that have historically been dominated by low input pastoral/rangeland agriculture will require the development of experience and understand of crop growth in an area where there is little experience of large scale broad acre cropping.

To facilitate the rapid development of the necessary experience and knowledge crop modelling can be used to simulate cropping scenarios and yield potential over long time frames in a matter of minutes. However, crop models area research tools, often with a significant number on user inputs which present an accessibility challenge for agricultural decisions makers. To make agricultural modelling accessible to decision makers, it can be incorporated into decision support platforms which reduce or automate inputs and allow users to focus on specific questions/decision scenarios (i.e. fertiliser or irrigation strategies).

The Agricultural Production Systems sIMulator (APSIM; Holzworth et al. 2014) is a cropping model which has been demonstrated to provide accurate crop modelling for a range of cereal and legume crops across a range of locations and production scenarios in the Northern Territory. CropARM is a decision support tool that is part of the ARMonline suite of decision support tools (www.ARMonline.com.au). It enables growers of broad acre crops to easily and quickly explore the impact of planting, fertilise and irrigation decisions on crop production over a 100 year time period. It utilises APSIM to generate cropping scenarios which can then be interrogated via a simple and accessible web interface.

The aim of this work was to add locations from the northern territory to the CropARM tools that provide coverage for crops of maize, sorghum, soybean, mungbean, peanuts and chickpeas.

6.3 Methods

6.3.1 Model description

APSIM version 7.10 (Holzworth et al. 2014) was used to undertake the crop simulations. Simulations used the maize, sorghum, soybean, mungbean, peanuts and chickpeas modules to represent these crops. Each simulation also included the soil nitrogen (Probert et al. 1998), soil water (Probert et al. 1998; Verberg and Bond, 2003) and surface organic matter modules (Probert et al. 1998).

6.3.2 Simulations

Simulations were undertaken for nine locations in the Northern Territory of Australia (Figure 6.1). These locations were chosen to represent areas where there is potential to develop irrigated broad acre cropping systems. Each location was simulated with six soil profiles (Table 6.1). Daily weather inputs for each location was sourced from the from the SILO climate database (Jeffrey et al. 2001). The management factors, implemented as a factorial in each crop simulation, are outlined in Table 6.2. Each combination of factors was run over 119 year period from 1901 to 2019. Each simulation included an annual reset which was implemented at planting to effectively create 119 individual year simulations.

The results from each simulation were grain yield (t/ha), grain protein (%), crop biomass (tDM/ha), in crop rainfall (mm), days from sowing to harvest, plant available soil water at harvest (mm), soil mineral nitrogen at harvest (kgN/ha), the average maximum and minimum air temperatures (^{o}C) four weeks after sowing, two weeks before and after anthesis and four weeks before harvest, the number of days where minimum air temperatures were less than 2^{o}C two weeks before and after anthesis (an indication of frost risk as per Robertson et al. 1999), total water used by the crop (mm) and total irrigation water applied to the crop (mm). The water use efficiency of grain yield and biomass production (kg/mm) were calculated from the simulation results.

Simulations were run on the University of Southern Queensland's Fawkes high performance computer, SGI C2112 system running Red hat enterprises linux version 6.9. At the conclusion of the simulations the results were summarised in R (version 3.5.2; R Core team 2018) and scatter plots of each simulation results vs year created to visually check the results. After the visual confirmation confirmed the simulations had run correctly the data was transferred to a SQL server version 2014 SP3) virtual machine using Python (version 3.8; https://www.python.org/).

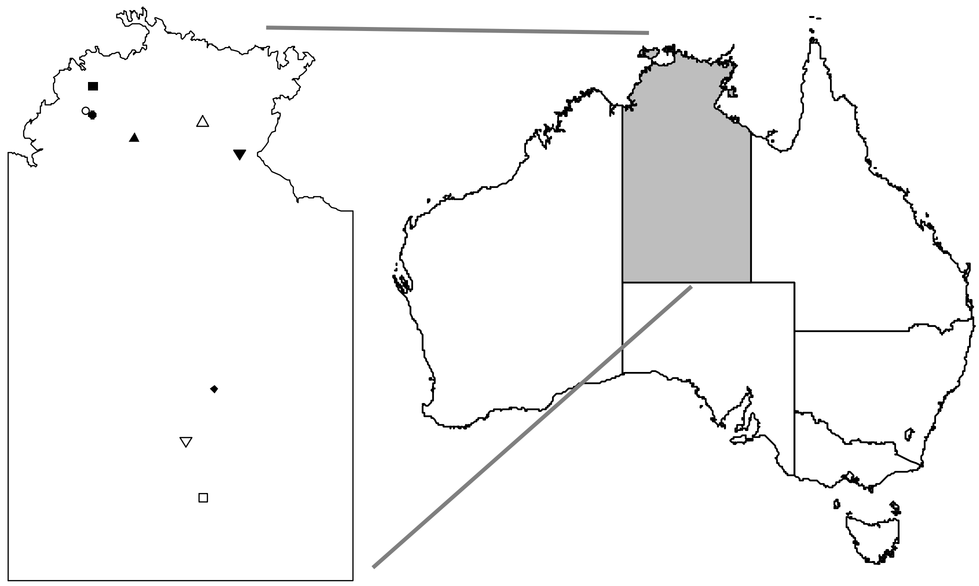

Fig. 6. 1 The location of the nine simulation locations used in this study and added to the CropARM decision support tool:

Douglas Daly (●), Katherine (▲), Tortilla flats (■), Ali Curung (◆), Flying fox station (▼), Mainoru Station (△), Oolloo Farms (▽), Rocky Hill Table Grapes (☐), Tipperary (○).

Table 6. 1 Soil water properties and soil carbon properties of the soils used in this study and added to the CropARM decision support tool.

Depth (mm)	Bulk density (g/cm^3)	Air dry water content (mm/mm)	Lower limit (mm/mm)	Drained upper limit (mm/mm)	Saturated water content (mm/mm)	Organic carbon (%)	Fraction of biomass carbon	Fraction of inert carbon
Brown Kandosol								
0-100	1.440	0.120	0.120	0.290	0.457	2.100	0.030	0.400
100-200	1.590	0.120	0.140	0.190	0.400	1.200	0.020	0.600
200-500	1.620	0.120	0.120	0.190	0.389	1.200	0.020	0.700
500-800	1.620	0.110	0.130	0.160	0.389	1.020	0.020	0.800
Deep Dermosol								
0-100	1.380	0.010	0.120	0.320	0.479	1.450	0.035	0.400
100-200	1.500	0.050	0.140	0.320	0.430	0.900	0.020	0.500
200-300	1.620	0.110	0.200	0.330	0.389	0.900	0.015	0.700
300-600	1.560	0.060	0.230	0.320	0.410	0.900	0.015	0.950
600-900	1.550	0.060	0.230	0.340	0.415	0.900	0.010	0.950
900-1200	1.560	0.040	0.230	0.330	0.410	0.900	0.010	0.950
Deep Vertosol								
0-100	1.100	0.220	0.250	0.370	0.580	0.900	0.035	0.400
100-200	1.240	0.060	0.300	0.430	0.490	0.790	0.020	0.500
200-300	1.240	0.130	0.280	0.400	0.530	0.700	0.015	0.700
300-600	1.240	0.020	0.320	0.450	0.460	0.450	0.015	0.950
600-900	1.240	0.010	0.310	0.470	0.480	0.270	0.010	0.950
900-1200	1.240	0.070	0.310	0.470	0.530	0.280	0.010	0.950
1200-1500	1.210	0.080	0.310	0.470	0.540	0.340	0.010	0.950
Hydrosol								
0-100	1.370	0.050	0.160	0.430	0.480	0.360	0.120	0.300
100-200	1.370	0.100	0.120	0.460	0.480	0.270	0.100	0.400
200-300	1.320	0.050	0.120	0.330	0.480	0.180	0.050	0.600
300-600	1.320	0.030	0.210	0.330	0.350	0.180	0.010	0.900
600-900	1.430	0.030	0.210	0.330	0.350	0.180	0.010	1.000
900-1200	1.404	0.030	0.210	0.330	0.350	0.180	0.010	1.000
1200-1500	1.530	0.030	0.210	0.300	0.350	0.180	0.010	1.000
Red Kandosol								
0-100	1.290	0.030	0.170	0.220	0.510	2.290	0.030	0.400
100-200	1.490	0.040	0.150	0.220	0.430	1.570	0.020	0.600
200-300	1.480	0.080	0.140	0.190	0.430	1.030	0.020	0.700
300-600	1.470	0.100	0.140	0.190	0.430	0.330	0.020	0.800
600-900	1.420	0.100	0.140	0.190	0.430	0.110	0.010	0.900
900-1200	1.500	0.100	0.140	0.190	0.430	0.070	0.010	0.900
1200-1500	1.470	0.090	0.170	0.220	0.430	0.050	0.010	1.000
Tenosol								
0-100	1.630	0.015	0.030	0.089	0.350	0.190	0.035	0.400
100-200	1.520	0.026	0.033	0.100	0.308	0.190	0.020	0.500
200-300	1.580	0.040	0.040	0.108	0.312	0.180	0.015	0.700
300-600	1.670	0.040	0.040	0.115	0.321	0.120	0.015	0.950
600-900	1.730	0.040	0.040	0.113	0.328	0.100	0.010	0.950
900-1200	1.730	0.040	0.040	0.105	0.346	0.060	0.010	0.950
1200-1500	1.730	0.040	0.040	0.110	0.342	0.160	0.010	0.950

Table 6. 2 The management options implemented as factorials for each crop simulation.

Crop	Genotype/ cultivar	Plant density (plants/m^2)	Sowing dates	Sowing fertiliser (kgN/ha)	Top dressing fertiliser (kgN/ha)	Irrigation
Maize	CRM* 94, CRM 100, CRM 114	4, 6, 8, 10	15-Oct, 15-Nov, 15-Dec, 15-Jan, 15-Feb, 15-Mar, 15-Apr, 15-May	0, 25, 50, 75, 100, 125, 150, 175, 200	0, 25, 50, 75, 100, 125, 150, 175, 200	Dryland Full Only at flowering, Vegetative only
Sorghum	Early, Medium, Late	4, 6, 8, 10, 12, 14	15-Oct, 15-Nov, 15-Dec, 15-Jan, 15-Feb, 15-Mar, 15-Apr	0, 25, 50, 75, 100	0, 25, 50, 75, 100	Dryland Full Only at flowering, Vegetative only
Soybean	MG† 5, MG 8, MG 10	15, 24, 35, 45	15-Oct, 15-Nov, 15-Dec, 15-Jan, 15-Feb, 15-Mar	NA	NA	Dryland Full Only at flowering, Vegetative only
Mungbean	Emerald, King, Green diamond	15, 25, 35, 45	15-Oct, 15-Nov, 15-Dec, 15-Jan, 15-Feb, 15-Mar	NA	NA	Dryland Full Only at flowering, Vegetative only
Peanut	VB97, Condor, Florunner	5, 7, 9, 12, 15	15-Oct, 15-Nov, 15-Dec, 15-Jan, 15-Feb, 15-Mar	NA	NA	Dryland Full Only at flowering, Vegetative only
Chickpea	Amethyst, Tyson, CPI56566	15, 25, 35, 45	15-May, 15-Jun, 15-Jul, 15-Aug, 15-Sep	NA	NA	Dryland Full Only at flowering, Vegetative only

*CRM: Crop Relative Maturity
†MG: Maturity group

6.3.3 Adaptation of the CropARM user interface

To account for the new locations and scenarios in in CropARM the interface was adapted. The new locations were added under the Northern Territory tab of the site selection menu. The scenario selection tab was modified in three ways. Firstly soil type was added as a selection option to account for the different soil types used in the simulations. Second a top dressing option for nitrogen was added for the sorghum and maize crops and third irrigation strategies were added.

6.4 Results and Discussion

To utilise the norther territory functionality in CropARM the user first navigates their web browser to www.armonline.com.au. From the ARMonline homepage the use selects the CropARM option from the list of decision support tools (Figure 6.2).

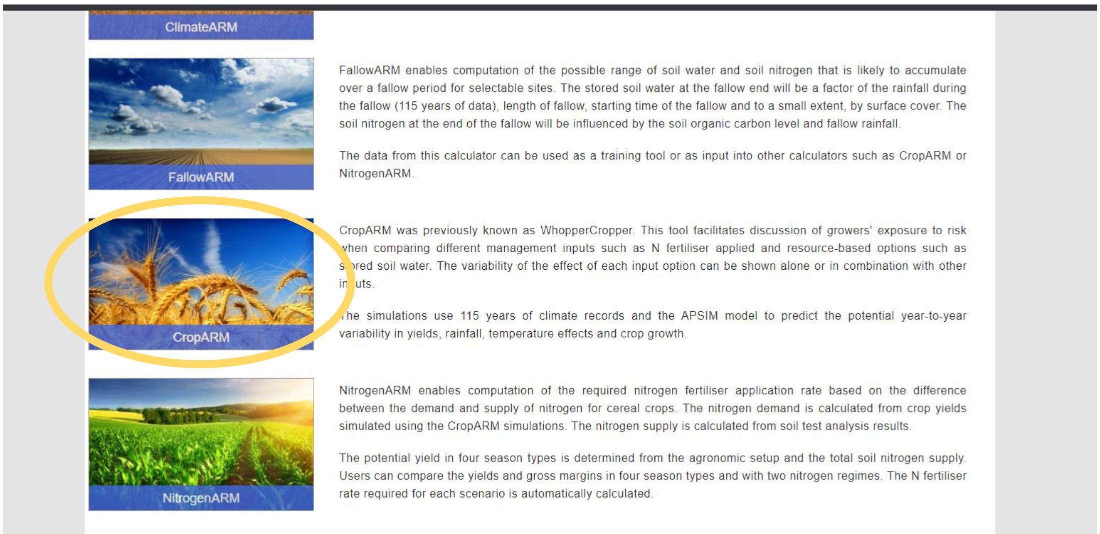

Fig. 6. 2 Selection of the CropARM tool in the suite of tools hosted by ARMonline.com.au.

To complete an analysis for a Northern Territory location using CropARM the user first selects a location. This is done by first selecting the sites option on the CropARM page (Figure 6.3) and then selecting a location from under the Norther Territory tab or by selecting a Norther Territory location via the interactive map. In this example Douglas Daly is used (Figure 6.4).

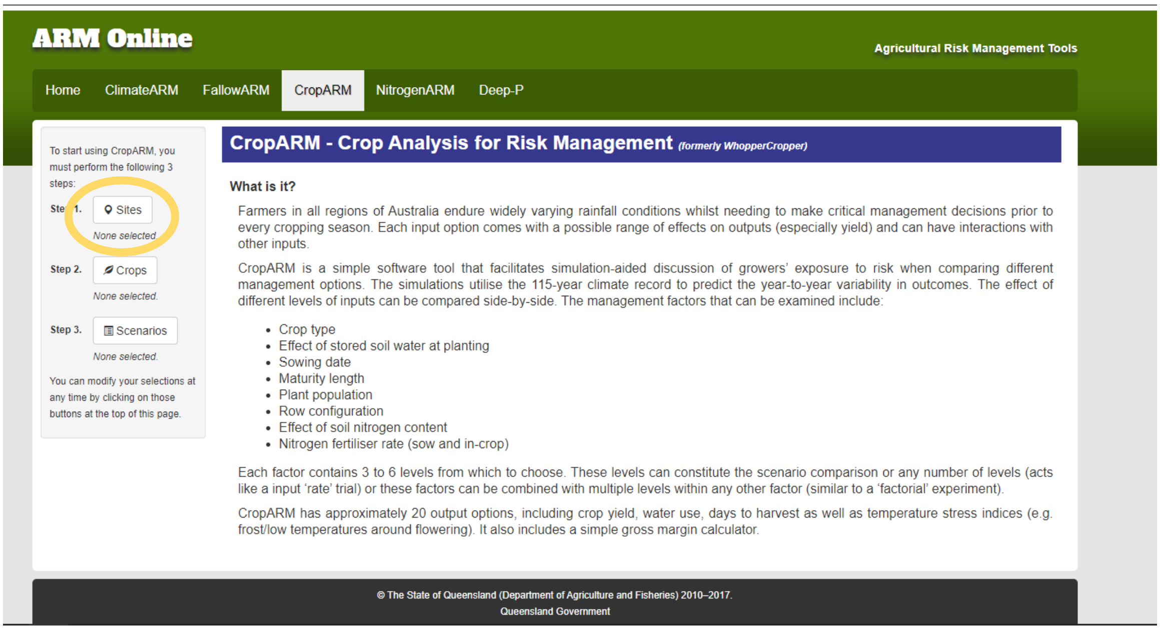

Fig. 6. 3 Selection of sites option on the CropARM page.

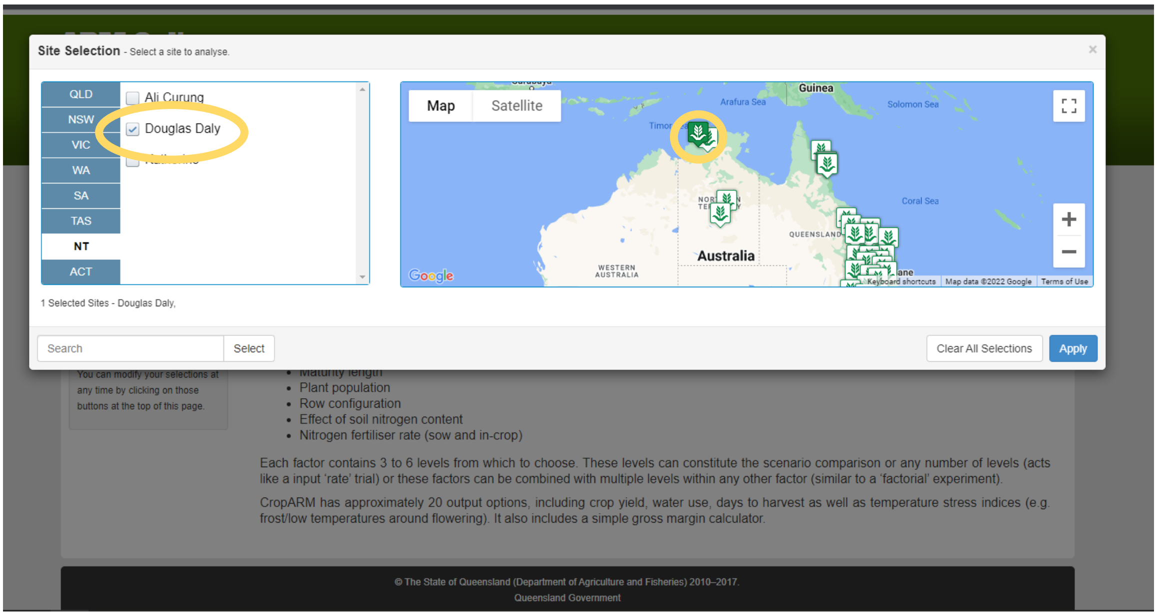

Fig. 6. 4 Selection of the Douglas Daly location for an analysis in CropARM.

From this point the user selects the crop. This is completed by clicking on the Crops option on the CropARM page (Figure 6.5). From there the crop of interest is selected from the resultant interface. In this example mungbean is selected (Figure 6.6).

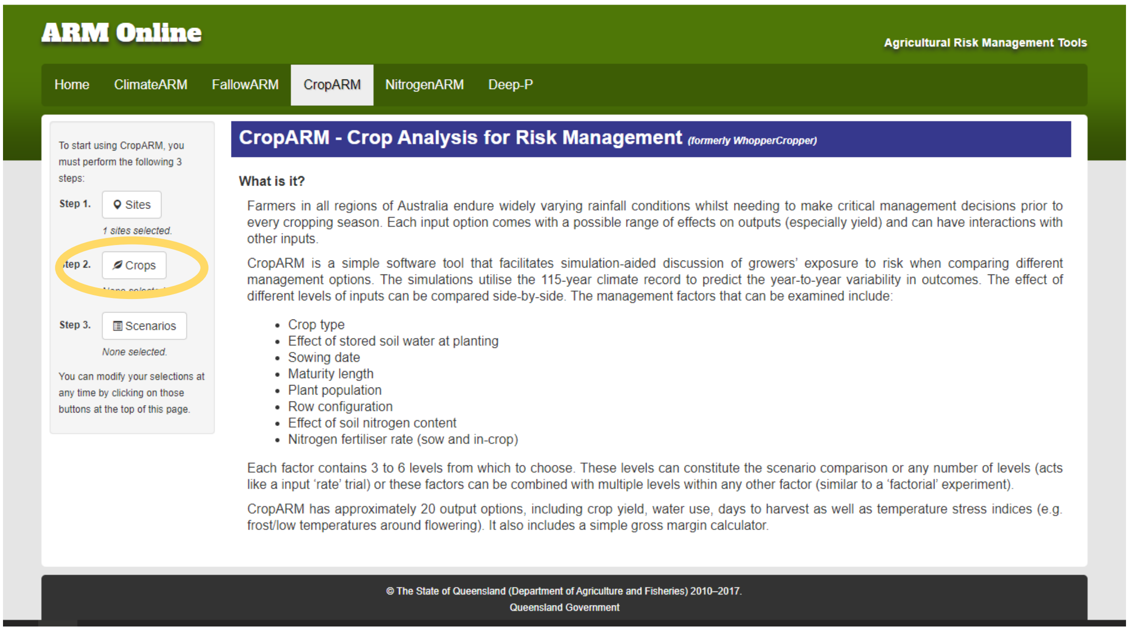

Fig. 6. 5 Selection of the Crops option on the CropARM page.

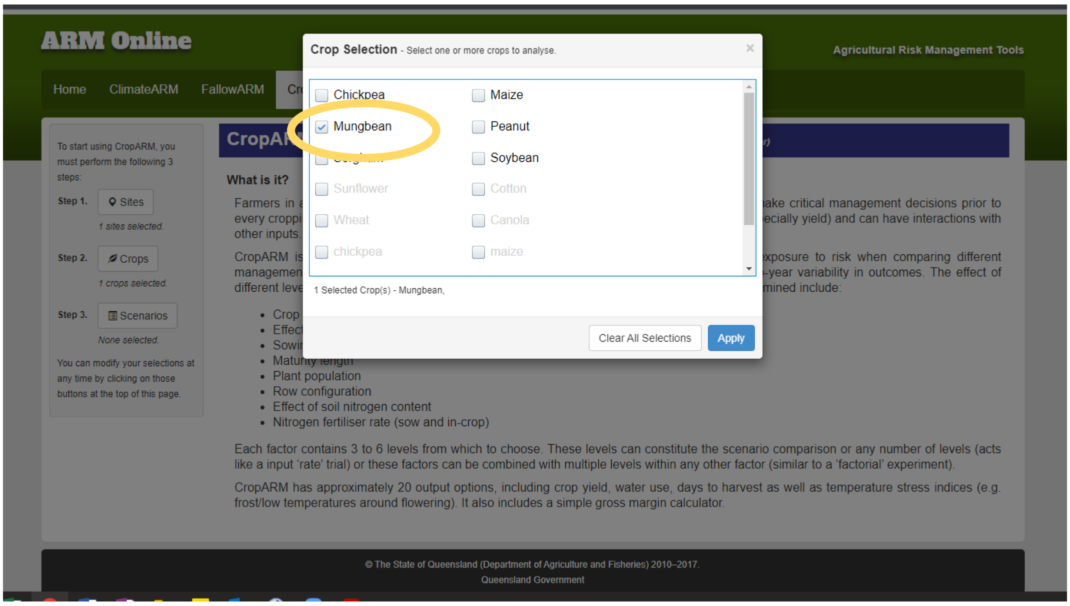

Fig. 6. 6 Selection of Mungbean for an analysis in CropARM.

After the site and crop is selected the scenarios for the analysis can be defined. The user selects the Scenarios option on the CropARM page (Figure 6.7). In the resultant interface the user then defines the scenario for analysis (Figure 6.8). In this example a range of sowing date options (October 15, November 15, December 15, January 15, February 15 and March 15) are analysed for an irrigated mungbean crop with the cultivar emerald planted at 35 plants/m^2 on a Deep Dermosol soil profile that is 60% full and 25 kg/ha of mineral soil nitrogen available.

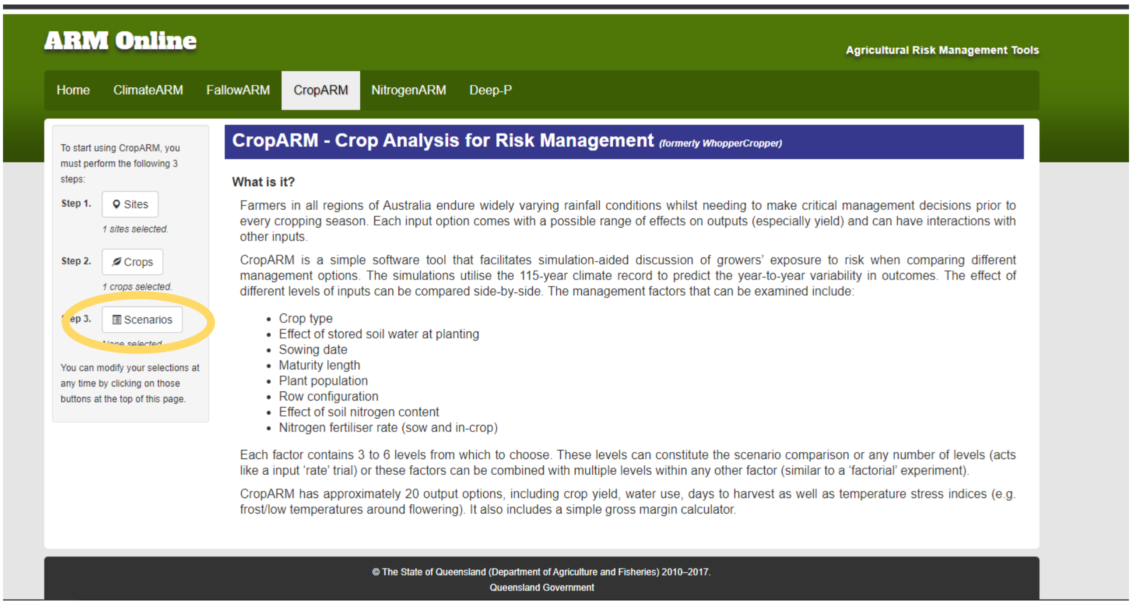

Fig. 6. 7 Selection of the scenarios option on the CropARM page.

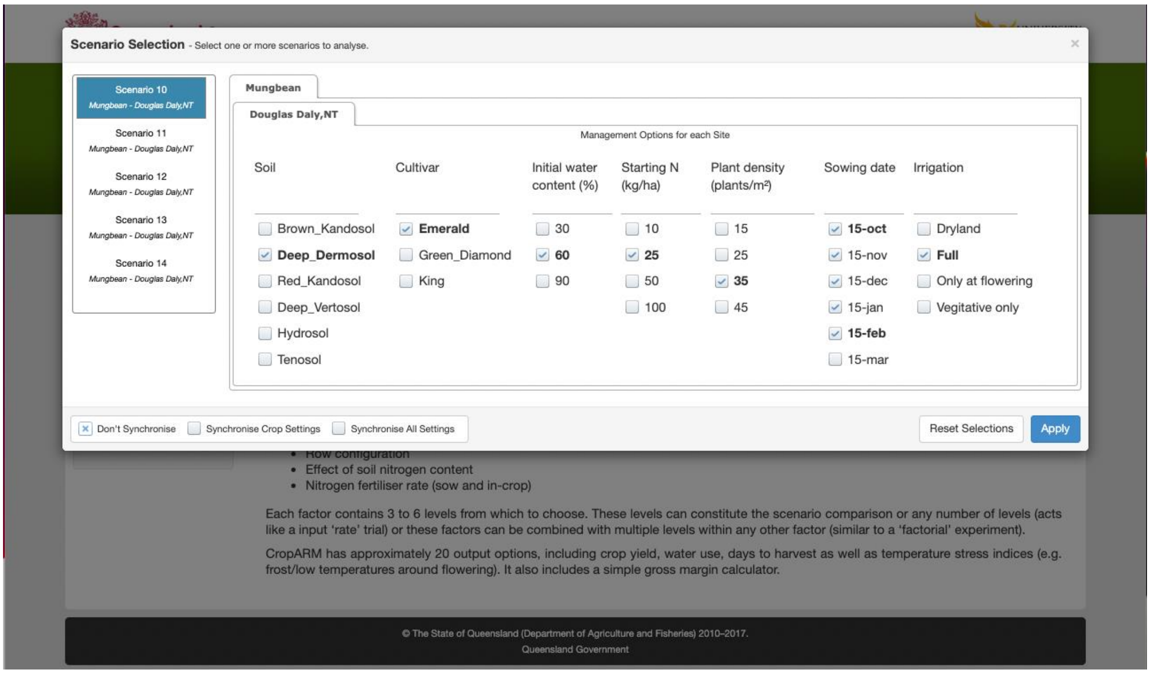

Fig. 6. 8 Selection of the scenarios for analysis.

The results of the analysis are then displayed (Figure 6.9). In this example it is clear that planning mungbeans on October 15 is the best option with later plantings through to January 15 having reduced yields. The February 15 sowing had greater yields compared to sowing on January 15. The user has the option to select how the results are displayed. The options available to the user are box and whisker plots, cumulative distribution plots, probability of exceedance plots and bar charts (Figure 10).

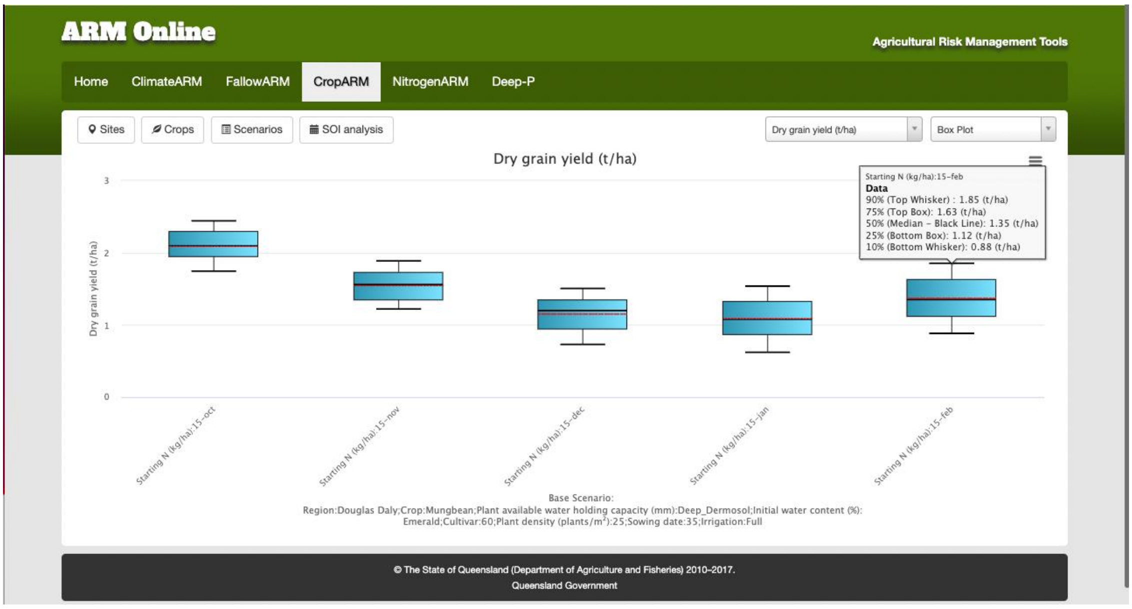

Fig. 6. 9 The results from the mungbean analysis presented as box and whisker plots

Fig. 6. 10 The different display options of box and whisker plots, cumulative distribution plots, probability of exceedance plots and bar charts for the results of the analysis.

6.5 Conclusions

The completion of this development effort provides to Northern Territory farmers and other agricultural decision makers the ability to quickly and easily analysis cropping scenarios for irrigated and dryland production of a range of cereal and grain legume crops. This will enable new participants in broad acre crop production to quickly develop the experience required to make appropriate cropping decisions through analysing crop management scenarios. This new functionality in CropARM will help establish broad acre cropping in the Northern Territory of Australia.

7. Performance and Applications of the APSIM Model for Broadacre Cropping of Peanut and Exploring the Potential of Chickpea

7.1 Summary

One of the objectives of the Cooperative Research Centre for Developing Northern Australia (CRCNA) project on the potential of broadacre cropping in the NT was to investigate what is required to develop a complete farming system of key tropical crops, including peanuts in the NT. As part of this project, management option scenarios for peanuts were to be developed using a crop modelling approach. Accepting those scenarios for providing guidance was contingent upon validation of the model in the NT environment. The APSIM classic (Version 7.10) of the peanut model was used to achieve this objective. As a dedicated small plot experiment being conducted as part of the project to validate the model was still incomplete, data from 27 past experiments and commercial crops were obtained from several unpublished sources. The model's accuracy in predicting pod yield was reasonable (up to 50%) with a root mean square error of 21%, which was within one standard error of observed pod yield. Given some uncertainties in the model inputs, including the assessment of crop maturity and the exact irrigation dates, this accuracy was acceptable. Scenarios of pod yields were developed for eight potential peanut growing locations in the NT, including Ali Curang, Douglas Daly, Katherine, Larrimah, Glen Arden, Tree, Tindal and Tipperary. The simulated pod yields were up to 10 t/ha but varied across different sowing times and locations. As expected, there was a difference in pod yield outcomes of short and full-season peanuts, with yields being more for full-season peanuts, but generally, full-season peanuts were less stable. The irrigation requirement to achieve high pod yields was around 8 ML/ha/crop/year. The duration of the crop, especially of full-season peanut, could be over 150 days in some sowings. There would be the risk of frost and heat stress in some sowings of a few locations in the southern NT that will limit the realisation of the yield potential. The pod yield scenarios suggested a possibility of peanut as a broadacre crop. Achieving this potential will require improved irrigation management, especially in the dry season, and control of pests and diseases in the wet season. As part of the project, the potential of chickpea as a dry season crop was also evaluated using the APSIM Chickpea model. The model output suggested that grain yield of up to 3t/ha can be realised with limited irrigation of up to 4 ML/ha. Consistent with the significant cultivation of chickpea at tropical latitudes, the crop has the potential to become a major broadacre crop in the NT region.

7.2 Introduction

Australia is barely able to produce 40% of the peanuts it consumes. Thus, a substantial demand-supply gap exists, which is being met through imports from countries where farm practices may not be as clean and green as they should be for quality-conscious Australian consumers. There is also considerable biosecurity (e.g., peanut smut imported from Argentina recently) and health risks related to aflatoxin-contaminated peanuts entering the Australian food chain. To reduce these imports, peanut area and yield need to increase by breeding better varieties and developing their agronomy.

Peanuts in Australia are primarily grown in the subtropical and tropical environments of Queensland. There is a need to expand pigeonpea cultivation into newer areas with more reliable rainfall and irrigation potential. The industry has been expanding into other regions in response to this need. The NT region represents one of the potential areas for expansion of the peanut industry, given the region's more reliable monsoonal rainfall pattern and greater availability of irrigation water from rivers and underground resources. There are potential sustainability benefits of having peanuts in the farming systems of the NT, given the crop is a prolific N fixer and can benefit crops grown in rotation. The Peanut Company of Australia commercially attempted to grow peanuts in the NT but was unsuccessful. A limited number of growers also tried to grow peanuts in the past. The fluctuations in the wet season rainfall, lack of adequate machinery, transport of produce and grower inexperience contributed to the lack of success (Marshall *et al.* 2014; Chauhan *et al.* 2015; Jakku *et al.* 2016) . Later research revealed that the environmental conditions experienced in the wet season were harsher, which significantly contributed to low yields and varying grades. There has been considerable agronomic research conducted on peanuts to grow in the NT, but the efforts to put them into a package have been lacking. Advances in crop simulation programs like APSIM (Agricultural Production Systems Simulator) provide a powerful tool that can be used to extend learnings from field research and build an understanding of short- and long-term risk profiles. It can identify critical management decisions, determine irrigation water demands and incorporate grower experience while developing an overall picture of the cropping potential of a region.

However, we need confidence in the model's performance to apply the model as a decision support tool. Researchers and the industry have successfully used the APSIM peanut model in Queensland, where peanuts are already grown commercially. The APSIM model was developed using the Plant Modelling Framework (PMF) of Brown et al. (2014). The model was developed from the original QNUT model (Hammer et al. 1995) with numerous enhancements. The model is described in the paper by Robertson et al. (2002). The industry has developed and used decision support tools like Afloman and Aquaman that use this framework (Chauhan et al. 2010; Chauhan et al. 2013). Recently, a new version peanut model, APSIM next generation, has been developed, which is expected to revolutionise the use of the peanut model as a decision support tool. The classic version of the model was mainly developed using data collected from subtropical regions of Kingaroy, Bundaberg, Gainesville, and Marianna (Florida, USA) and in the tropics at Kairi in Queensland and Kununurra in Western Australia. However, the model's performance has not been assessed in the NT. The CRCNA project on 'Potential for Broadacre cropping in the NT' provided this opportunity. This work focuses only on the classic version of the peanut model, as the APSIM next-generation model is a very recent development. Validating APSIM to work in the semi-arid tropics and linking this with past agronomic research will start developing complete farming systems for the NT.

This report also summarises the work on developing scenarios of peanut production in the NT on which a report was previously submitted as a milestone report.

Objective

The objective of this study was to evaluate the performance of the APSIM peanut model and apply it to develop crop production scenarios for eight critical locations in the NT.

7.3 Methodology

7.3.1 Model validation

Peanut trial at Katherine in 2022

A field trial was initiated at the Katherine Research Farm (-14.47 °S, 132.31° E) during the summer season of 2021-22 to assess the performance of the APSIM peanut model. The un-replicated trial was planted with two commercial cultivars, Alloway and Kairi, on 11th Feb 2022 and 7th Mar 2022. The soil of the farm is a Tippera loam. The trial was irrigated using digitally controlled overhead irrigation. At both planting times, the site was prepared by irrigating before sowing. Muriate of Potash (80kg/Ha), Super guano (sulphur 270 kg/Ha) and trace elements were spread over the surface. The soil was then chisel ploughed to break up hard set clods (photo 1A), and then rotary hoed to produce a good seed bed and incorporate fertiliser. A 300kg/Ha dose of Calcium nitrate was applied to both plantings and again on 18th Mar 2022. On 4th Apr 2022, the trial received 500 gm of Gypsum per row (550 kg/ha).

Photo. 7. 1 Tillage activities before and at planting

Photo. 7. 2 Hand planting arrangement. The lines show inter row spacing of 90 cm.

Photo. 7. 3 Crop at emergence. The population achieved was remarkably close to the target population of 15 plants/m2.

Planting was done by hand. Two commercial varieties, Alloway and Kaira, were planted @ 15 p seeds/Ha. Plot sizes for each variety were four rows spaced at 90 cm by 10 ms. After planting, Dual Gold Active (Metolachlor) was applied as a pre-emergent herbicide at 1.9lt/Ha. This was incorporated with irrigation.

Photo. 7. 4 Peanut canopy development in the early (background) and late sowing.

Photo. 7. 5 Partial and complete canopy closures in the date of sowing trial planted on 11th Feb and 2nd Mar 2022 at Katherine.

During the growing period, periodic observations on crop flowering canopy cover were recorded. APSIM predicted 50% flowering was about nine days later than the start of observed flowering date of 7^{th} Mar 2022 and 29^{th} Mar 2022 for 11th Feb and 2^{nd} Mar sowings, respectively. This nine-day gap was the time required for the crop from the start of flowering to reach 50% flowering as has also been observed in the subtropical environment of Kingaroy. As the crop was expected to be harvested in June/July, model relevant data were still being compiled for the model when preparing this report. Therefore, data collected in previously conducted well-managed farm trials of >25 ha was used to validate the model.

This is described in the next section.

7.3.2 Commercial plantings at Katherine in 2007

The peanut industry established several commercial peanut plots in 2007 at Eagle Park, 40 km near Katherine. The soils of this farm have been characterised for use in the APSIM under a different project. Data from six commercial scales (>30 ha) field trial data, which were available, were used to evaluate the model. The crop in these plots was grown using standard agronomy, including a plant population of 15 plants/m^2, fertilisation with muriate of potash @ 90kg/ha and triple super phosphate

@ 150 kg/ha and gypsum @ 960 kg/ha and irrigation using pivot irrigation. Peanut cultivar Holt was planted in all sowings, except the 12th of Feb 2007 planting when Menzies of similar maturity as Holt was planted. Timings of sowing, harvesting, crop duration and cumulative thermal time, irrigation applied, and in-season rain are given in Table 7.1. It is unclear if there was an assessment of maturity before the plots were harvested as thermal time accumulation at the time of digging differed considerably in different sowings.

Photo. 7. 6 Five pivots at the Eagle Park farm, 40 Km from Katherine, on which commercial (>30 ha) peanuts were grown in 2007.

Photo. 7. 7 A close-up picture of a peanut crop at one of the pivots in 2007 at Eagle Park near Katherine

Table 7. 1 Dates of sowing, digging, duration of the crop and cumulative thermal time, total irrigation (irrig.) applied, in-season rain and full water for the harvest. The plant population used was 15 plants/m2

Date of	Date of	Duration	Thermal time	Total irrig.	Total rain	Total water
Sowing	digging	(days)	(°Cd)	(ML/ha)	(mm)	(ML/ha)
2/02/2007	8/06/2007	126	1850	3.87	476	8.63
11/02/2007	5/06/2007	114	1671	3.26	392	7.18
12/02/2007a	16/06/2007	124	1789	3.4	392	7.32
18/02/2007	28/06/2007	130	1832	3.24	392	7.16
6/03/2007	16/08/2007	163	2140	6.55	387	10.42
12/04/2007	1/10/2007	172	2137	9.75	724	16.99

Cultivar Menzies was used. In all other sowings, Holt was sown.

7.3.3 Data collected at Douglas Daly

Data of 21 experiments on peanuts conducted at Douglas Daly Research Farm from 1981 to 2001 by Chris Flint. Chris Ham and Col Martin were used. The dates of sowings and other details of these trials are given in Table 7.2. The research station has sandy blain and red earth soils. The experiments compared cultivars, agronomy and irrigation, nutrition, and tillage. These experiments were harvested when the crop accumulated 1747-to-2200-degree days and covered wet and dry seasons. Generally, Florunner parameterised in APSIM was always present, except in the 1981 sowing trial of row configuration and plant population effect when only Virginia-bunch and Red Spanish were used. However, the trial was harvested 136 days after sowing. Hence parameters of longer season cultivars were used as a proxy for this cultivar.

7.3.4 Weather data

Weather data for simulations were collected using the data drill matching the site coordinates from the SILO Website (www.longpaddock.qld.gov.au/silo/point-data/). These data included maximum and minimum temperatures, rainfall and solar radiation required as input for the APSIM peanut model. The website generates an APSIM compatible weather file of the requested coordinates, duration commencing 1889 up to a day before the date of request.

7.3.5 Soil characterisation

The soil file for Eagle Park was generated using soil samples collected in the project' Agriculture transforming to adapt to climate change: peanut industry expansion in the NT as a blueprint' led by Dr Peter Thorburn of CSIRO. Soils hold 140 mm water to a 90 cm depth (Table 7.3). In both places, the soils are sandy or red earth, which are freely draining; the SWCON was increased from 0.4 (a value commonly used for less draining black vertosols) to 0.9, which was consistent with similar increases for Kingaroy Ferrosols. Model runs, irrespective of soil, were initiated with 66 % starting moisture which was midway to 80%, the maximum at the time of sowing and 50%, the lowest amount that allows good establishment.

Table 7. 2 Details of past trial conducted in the wet (ws) and dry seasons (ds) at Douglas Dalya

Sowing date	Objective
18-Jan-81	Cultivar evaluation under rainfed conditions (1981-82 ws)
23-Dec-81	Population and arrangement (1981-82 ws)
23-Dec-81	Population and arrangement experiment (1981-82 wet season)
21-Dec-82	Cultivar evaluation (1983-84 wet season)
28-Dec-82	Cultivar evaluation (1982-83 ws)
28-Dec-82	Cultivar evaluation (1982-83 ws)
28-Dec-82	Cultivar evaluation (1983-84 ws)
21-Dec-83	Alar on morphology and yield (1983/84 ws).
03-Jan-84	Alar on morphology and yield (1983/84 ws).
21-Dec-84	Cultivar evaluation (1984-85 ws)
25-Dec-85	irrigation, hilling and cultivar on yield, efficiency of digging and quality (1985-86 ws)
25-Dec-85	irrigation, hilling and cultivar on yield, efficiency of digging and quality (1985-86 ws)
18-Dec-86	Yield response of Virginia bunch to irrigation and Alar (1986-87 ws)
18-Dec-86	Yield response of Virginia bunch to irrigation and Alar (1986-87 ws)
22-Dec-86	Growth resultant (Alar) (1985/86 ws)
23-Dec-87	Tillage system (1987-88 ws)
30-May-98	Herbicides (1998 ds)
17-Mar-99	Herbicides (1999 ds)
24-Mar-00	Final report for 2000 dry season nutrition trial (2000 ds)
13-Mar-01	Macronutrients for peanuts on Ruby Blain soil (2001 ds)
12-Mar-02	Season report (2002 ds)

[a]In the model, the plant population, sowing date, irrigation regime and harvest dates that were described for the experiment were used (see appendix).

Table 7. 3 Soil profile properties used in simulation. Peanut roots explored up to 90 cm layer.

Depth mm	Air_Dry mm/mm	LL15 mm/mm	DuLL mm/mm	Sat mm/mm	Sw mm/mm	BD g/cc	Runoff wf	SWCON
0-100	0. 0.005	0.010	0.190	0.334	0.154	1.68	0.61	0.9
100-200	0.005	0.010	0.180	0.334	0.146	1.73	0.24	0.9
200-300	0.005	0.010	0.130	0.340	0.106	1.70	0.10	0.9
300-400	0.005	0.020	0.160	0.343	0.132	1.74	0.04	0.9
400-600	0.005	0.020	0.170	0.332	0.140	1.77	0.01	0.9
600-900	0.005	0.020	0.185	0.370	0.152	1.67	0.00	0.9
900-1200	0.005	0.020	0.200	0.398	0.164	1.54	0.00	0.9
1200-1500	0.005	0.025	0.210	0.398	0.173	1.54	0.00	0.9
1500-2000	0.005	0.025	0.200	0.398	0.165	1.54	0.00	0.9

Photo. 7. 8 A peanut crop growing under a pivot in 2001 at Douglas Daly.

7.3.6 Validation data for model evaluation

The crop data from both locations were pooled together to evaluate the model. Pod yields at Katherine were from the entire trial area >30 ha planted. As these were commercial plantings, no subsamples were planned to be taken during crop growth or harvest. At Douglas Daly, pod yields were hand-harvested from a sample from a 1 to 2 m2 area of experimental treatments.

7.3.7 Input file generation

The APSIM peanut model (classic version 7.10) predicts peanut growth and yield in response to soil, whether genetic and management input in a daily time step (Holzworth et al. 2014) and (Robertson et al. 2002) was used. For simulating Katherine crops, Holt and Menzies parameters were used. These have been previously developed using data collected in southeast Queensland. Both cultivars are a runner type mature in 18-24 Weeks depending upon seasonal temperatures.

At Douglas Daly, Florunner was used in all experiments. Even Virginia bunch used in one of the experiments was harvested beyond its thermal time target. Hence, and hence parameters of Florunner were used. In trials where harvesting of Florunner was also substantially delayed beyond the thermal time target, parameters of Menzies were used. If the crop was dug before the maturity of Florunner, simulation was terminated on the day of the crop being dug.

7.3.8 Scenario generation

The Agricultural Production Systems Simulator (APSIM Classic version 7.10) was configured to simulate pod yield in monthly sowings at three soil types for eight locations (Figure 7.1, Table 7.4). The climatic data of nearby patched point stations (Table 7.1) and interpolated data (Glen Arden) were used as input to run the model. The climatic data were obtained from the silo website (www.longpaddock.qld.gov.au/silo/point-data/). The soil data used were of three generic soils with 151, 125- and 75-mm plant available water holding capacities obtained from the AMSOIL database. It was assumed that peanuts would be predominantly grown with irrigation on these soils in the NT region. An auto irrigation input rule ensured 40 mm irrigation whenever the deficit reached 40 mm. An irrigation efficiency of 100% was assumed. APSIM was run in a factorial set-up using short season and full-season peanuts grown in the middle of each month for 15 seeds m2 sown at 25 mm deep. The simulation set-up generated 576 output files (8 locations x 12 sowing times x 3 soil types x two high oleic peanut cultivars, including full-season Holt and short-season Taabinga) to develop a database. It was processed using the R program (Team 2013).

Table 7. 4 Details of the location used in developing peanut pod yield scenarios.

Location	Station number	Latitude/Longitude	Climate data type
Ali Curung	015502	-21.00/134.40	Patch point
Douglas Daly	014901	-13.83/131.19	Patch point
Katherine	014910	-14.47/132.31	Patch point
Larrimah	014612	-15.57/133.21	Patch point
Glen Arden NJ	NA	-20.95/134.05	Interpolated
Tee Tree	015520	-22.13/133.42	Patch point
Tindal	014932	-14.52/132.38	Patch point
Tipperary	014925	-13.74/131.04	Patch point

NA: interpolated data of nearby grid used.

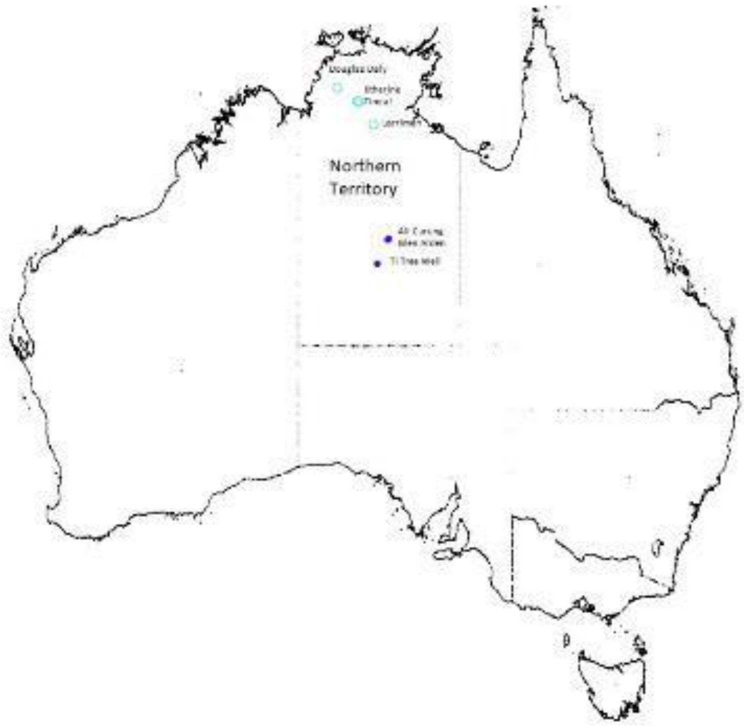

Fig. 7. 1 Locations of the Northern Territory used for developing peanut scenarios using the APSIM model.

Pod yields, irrigation requirements and days after sowing scenarios were visualised as box plots. Each box plot (Figure 7.2) typically depicts upper and lower limits representing 25th and 75th percentiles, also known as the first and third quartiles (Figure 7.2). Half of the data points fall between these two quartiles, and the distance indicates the interquartile range. The median point (point C) is the median data point. The whiskers D and E represent the data range; points outside this are outliers. The outliers are computed as the data > 75th percentile plus 1.5 times the interquartile range or < 25th percentile minus 1.5 times the interquartile range (Figure 7.2).

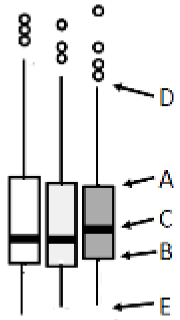

Fig. 7. 2 Box and whisker information used in the scenarios

7.4 Results

7.4.1 Pod yield and dry matter accumulation during crop growth

Dry matter production and partitioning were compared for Douglas Daly for the 1983/84 and 1984/85 seasons (Figure 7.3). Observed and predicted pod yields matched well in both seasons; biomass simulation was like observed values in 1984/84.

7.4.2 Thermal time accumulation at harvest

The digging dates at Katherine were not always as per the thermal time targets of the cultivar grown and varied between 1677 - 2159 ^{0}Cd. The observed yield was significantly related to variation in thermal time accumulation at harvest (Figure 7.4a). Still, the slopes of the relationship were in the opposite direction of the simulated pod yield (Figure 7.4b). At Douglas Daly, a similar variation in thermal time targets (1747 to 2200 °Cd) at the harvest times was observed, but this variation was not related to the observed or predicted yield, as at Katherine. The decline in observed pod yield with increased thermal time suggests there may have been growing difficulty in recovering pods from the soil with time.

7.4.3 Pod yield at harvest

The hand-harvested observed pod yields at Douglas Daly ranged from 2.3 to 6.9 t/ha, whereas the predicted pod yields ranged from 3 to 7.6 t/ha (Figure 7.5). At Katherine, the commercial pod yields ranged from 3.0 to 5.0 t/ha, and the predicted pod yields ranged from 3.0 to 7.0 t/ha. The average predicted pod yield was slightly higher than the observed ones at both locations. The model does not simulate pests and diseases or loss of pod yield due to machine harvesting (commercial yields at Katherine were estimated from machine harvest) from the entire cropped area. Also, pod yield losses were reported due to bird damage in standing and harvesting crops in a few experiments, especially in the later years as the birds got skilled in digging and breaking pods. An appreciable discrepancy was observed and predicted yield in Katherine's two dry season commercial plantings (two rightmost pairs of bars in Figure

7.5). At Douglas Daly, APSIM simulated pod yields were only slightly more, except in 1986 to 1988 trials with growth regulators when observed pod yields were more.

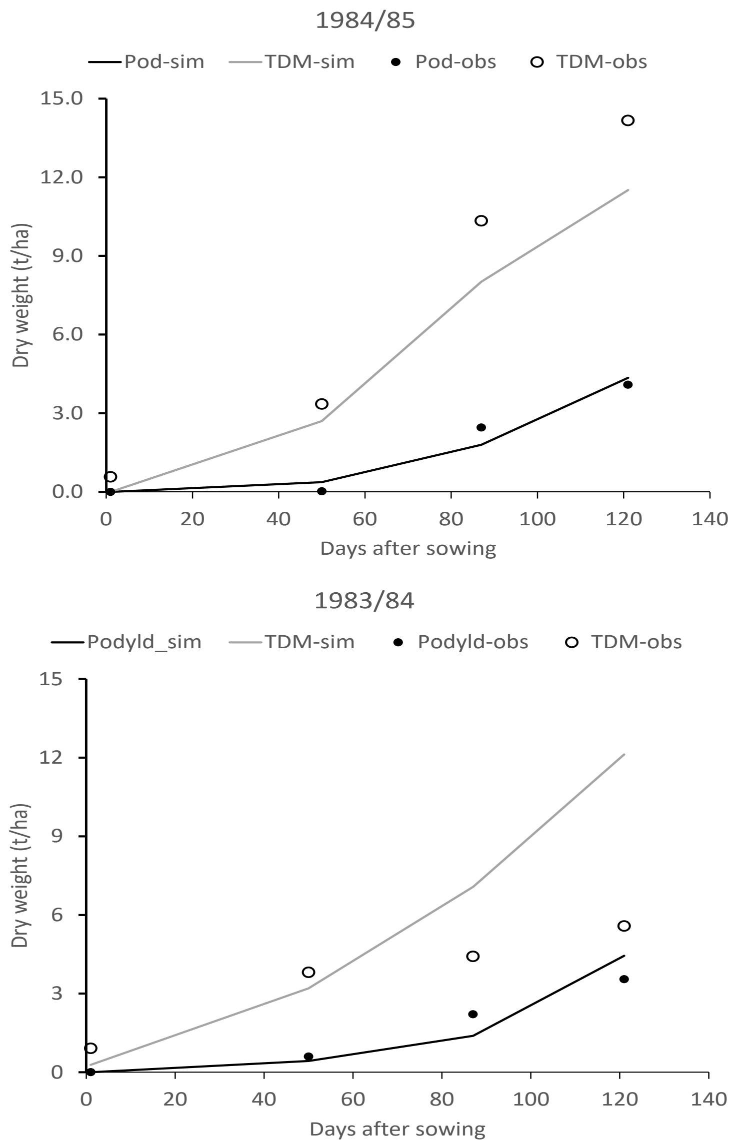

Fig. 7. 3 Dry matter (TDM) and pod weight accumulation in 1983/84 (a) and 1984/85 (b) seasons at Douglas Daly. Sowings for these two crops were done on 21st Dec of the respective season.

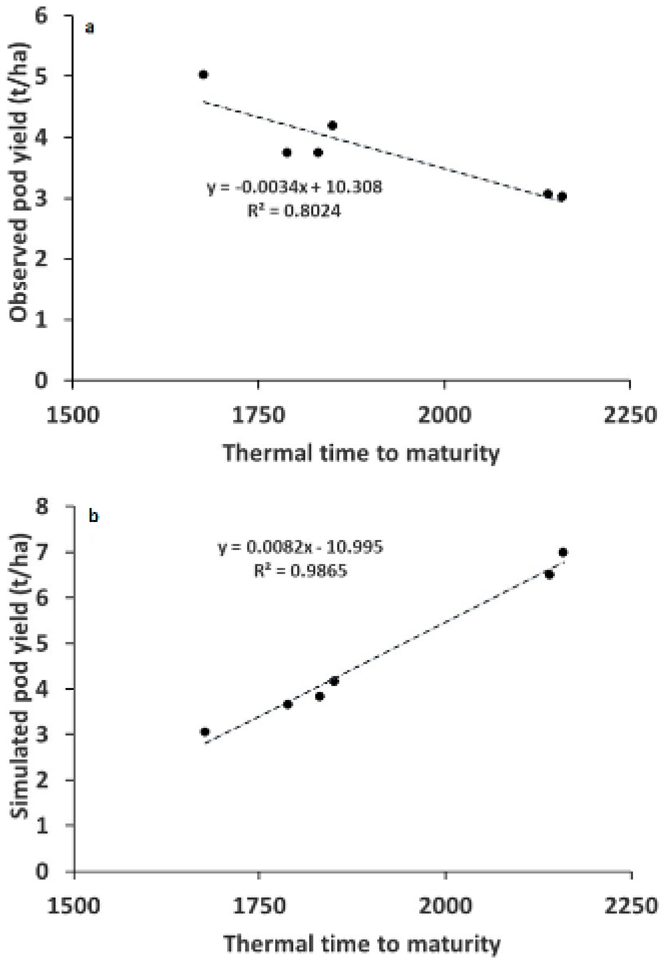

Fig. 7. 4 The relationship of observed (a) and simulated (b) trends with accumulated thermal times at harvest at Katherine.

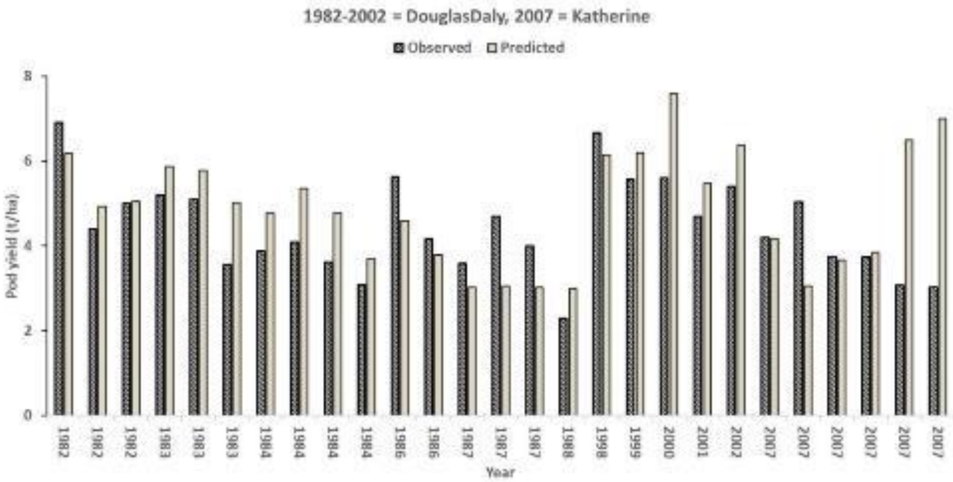

Fig. 7. 5 Observed and predicted yields at Douglas Daly between 1982 and 2002 (21 leftmost bars of observed and expected bars) and at Katherine in 2007 (six rightmost bars of observed and predicted pod yield bars).

7.4.4 Model evaluation

The observed pod yield data were compared with APSIM simulated data. The null hypothesis being tested for this analysis was that the APSIM Peanut model could well

account for weather, soil, and agronomy practices (sowing time) affecting pod yield. Known values of sowing dates, plant population, cultivar and irrigation were the inputs for predicting pod yields. Weather data were obtained from the silo website, which generally matched well with those described for the experiments. These experiments spanned several seasons in two key locations, Douglas Daly and Katherine in the NT. These datasets were not used in model development and can be considered independent. It was assumed that the actual crop was harvested after an adequate assessment of maturity (when >80% of the mesocarp of the pods has turned dark). Hence the model was run from sowing to digging dates.
The model predicted yield for experiments given in Tables 1 and 2 generally followed the trend of the observed pod yield (Figure 7.6). The R^2 of the relationship of combined data of two locations was 0.45 after excluding two outliers of Katherine, where observed yields were less than half of the predicted yield were considered outliers and therefore excluded from this analysis (Figure 7.5). The regression and the slope were significant (p<0.01). The points were on both sides of the 1:1 line, and with the intercept being non-significant, the relationship seems to meet the typical requirement of a good model. In a similar relationship only for Douglas Daly, the predicted yield accounted for 50% variation in pod yield as pod yield data were from hand-harvested samples (the trend line not shown). However, the overall relationship in slope or intercept did not change. The regression of the combined plot of observed and predicted yield indicated the root mean square error (RMSE) of 21%, which was within one standard error of the practical pod yield.

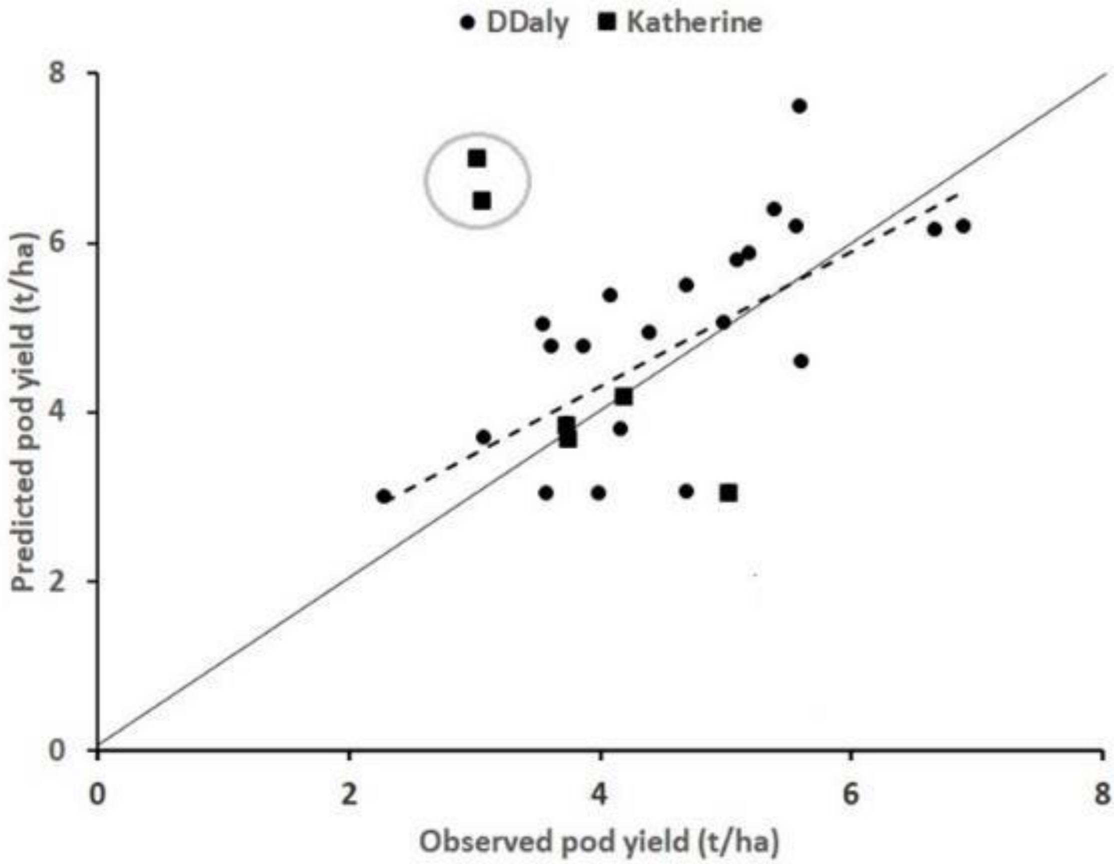

Fig. 7. 6 Observed vs. predicted pod yields in 21 peanut crops at Douglas Daly and 6 peanut crops at Katherine.

The open points in the grey circle are those of two dry season plantings at Katherine, in which, for unknown reasons, the observed pod yields were less than half of the simulated pod yields and hence were excluded from the regression. The relationship can be described by equation y = 0.80 (±0.18) * X, n = 28, R2 = 0.45** with intercept being non-significant. The RMSE was 21%. The slope of the relationship was significant ($p<0.001$), but the intercept was not. Characterisation of the environment of locations chosen for scenario generation.

Mean monthly rainfall varied across the eight locations (Table 7.5). Ali Curung, Glen Arden, and Ti Tree appeared relatively dry even during the wet season commencing in October compared to the remaining five locations, including Douglas Daly, Katherine, Larrimah, Tee Tree, Tindal and Tipperary. These five locations had good rainfall but were relatively dry between April and October. The high rainfall locations of Katherine, Tindall, Larrimah, and Tipperary had a good rain for rainfed cropping until March.

At several locations, the maximum temperature exceeds 39°C, which can affect the reproductive development of peanuts (Prasad *et al.* 1999; Boote *et al.* 2018). In Table 5, months with high heat risk are those in which the mean maximum temperature is shown in bold font. Accordingly, most months in the wet season will be prone to high heat risk, mainly where water may be limited due to failure of rains or timely irrigation. Solar radiation was reasonably high at most locations, around 20 MJ/m^2/day. In some locations, solar radiation was slightly less during the wet season due to overcast skies (Table 7.5).

Most locations were reasonably warm for establishing a crop (mean temperature >18 °C), and occasional frosts at Ali Curung, Glen Arden and Ti Tree during the growing season. Occasional frosts could cause a partial crop failure in some sowings at these three locations. Minimum temperatures have been highlighted with a bold font for months with a high risk of frosts (Table 5). Accordingly, only Katherine and Tipperary appeared free from frost risk; other locations had frost risk of varying degrees (Table 7.5).

7.4.5 Peanut pod yield scenarios

Simulated pod yields of the full-season cultivar (comparable to Holt), as expected, exceeded by about 25 to 29% that of the short-season cultivar (similar to Taabinga/Early Bunch) due to differences in their growing durations (Figure 7.9 to 7.14). However, the full-season peanut was relatively less stable, as suggested by the length of the box plot, especially in some environments and sowings. Simulated pod yields of full-season cultivar were ~10 t/ha at Ali Curung and Glen Arden in Feb/March sowings.

Pod yields were generally lower as the soil water holding capacity decreased. While the difference in pod yield on 151- and 125-mm soil was slight, the soil with 75-mm plant available water was distinctly inferior for pod yield. There was little difference in time to maturity at three different soil types. Usually, peanut takes longer to mature if it experiences drought.

7.4.6 Irrigation requirement

To obtain pod yield levels > 8 t/ha, the crop requires 7 to 10 ML of water (Figure 7.7 to 7.14). Irrigation requirement during the wet season was considerably less in more tropical locations due to higher in-season rainfall. The irrigation requirement of Ali Curung and Glen Arden remained high even in the wetter season due to lower amounts of rain. There is considerable interannual variation in the irrigation requirement related to rainfall.

7.4.7 Days to maturity

Days to maturity were generally longer for the dry season crops than for the wet season crops. The short season peanuts naturally matured 3 to 4 four weeks earlier than full-season peanuts. Growing short season peanuts at Ali Curung, Glen Arden will be desirable as full-season peanuts though they give a high pod yield, will take much longer to mature due to cooler climatic conditions. Occasionally they may have a greater chance of frost during the winter months from May to August (Figure 7.3). In several months of sowings, however, the crop may experience high (>39 °C) temperatures which could severely affect pod yield and its quality, as has been reported in some studies (Prasad et al. 1999). Months prone to heat stress and frost risk have been shown to have the bold face of maximum and minimum temperature values in Table 7.2. The longer growing season may also entail greater input of fungicides and other pest control measures in the Ali Curung environment.

Table 7. 5 Monthly averages of max and min temperatures, rainfall (rain) and radiation (radn) at eight Northern Territory locations evaluated for broad acre cropping potential of peanuts. Months with max and min temperatures in a bold font are prone heat stress (>39°C) and frosts (<=2°C), respectively.

Sowing	Maxt C	MinT C	Rain mm	Radn MJ/m^2/d	Maxt C	MinT C	Rain mm	Radn MJ/m^2/d	Maxt C	MinT C	Rain mm	Radn MJ/m^2/d	Maxt C	MinT C	Rain mm	Radn MJ/m^2/d
Ali Curung					Douglas Daly				Glen Arden				Katherine			
Jan	37.7	24.2	77	24.2	33.8	24.0	285	17.2	37.6	24.2	80	24.2	34.7	24.2	252	17.5
Feb	36.6	23.6	81	23.2	33.4	23.9	278	17.0	36.6	23.6	78	23.2	34.3	23.9	232	17.0
Mar	35.0	21.6	36	22.2	34.0	23.4	221	18.2	35.1	21.7	37	22.2	34.5	23.2	163	18.1
Apr	31.8	17.7	16	20.6	34.3	21.1	51	19.5	31.8	17.8	15	20.6	34.2	20.7	38	19.2
May	27.0	13.1	16	17.6	33.0	17.9	8	19.1	27.1	13.3	15	17.6	32.2	17.5	4	18.7
Jun	24.0	9.5	5	16.8	31.1	14.9	2	18.9	24.0	9.7	5	16.8	30.2	14.3	1	18.5
Jul	24.0	8.6	7	18.1	31.3	14.1	2	19.9	24.0	8.8	6	18.1	30.3	13.5	2	19.6
Aug	26.8	10.5	3	21.2	33.2	15.5	1	22.0	26.8	10.7	3	21.2	32.5	15.2	0	22.0
Sep	31.2	15.0	9	23.8	36.1	19.6	5	23.1	31.2	15.2	8	23.8	35.7	19.8	5	23.3
Oct	34.7	19.0	16	25.6	37.4	22.9	37	23.3	34.7	19.2	15	25.6	37.8	23.7	25	23.5
Nov	36.7	21.9	26	25.8	36.8	24.0	119	21.8	36.7	22.0	25	25.8	37.7	24.8	89	22.0
Dec	37.7	23.5	53	25.0	35.2	24.2	212	19.2	37.6	23.6	50	25.0	36.2	24.6	187	19.4
Larrimah									Tindal				Tipperary			Ti Tree
Jan	35.3	24.1	209	18.2	33.4	24.1	246	17.4	33.5	23.9	314	17.2	37.1	22.8	68	25.0
Feb	34.7	23.7	201	17.5	34.0	23.8	232	17.0	33.1	23.8	298	17.0	35.9	22.2	62	23.8
Mar	34.4	22.7	151	18.3	34.2	23.1	166	18.1	33.7	23.4	232	18.2	34.0	19.9	34	22.4
Apr	34.0	20.0	29	19.5	33.9	20.6	36	19.2	34.1	21.3	56	19.5	30.2	15.5	17	20.3
May	31.7	16.5	9	18.5	31.9	17.4	4	18.6	32.7	18.2	8	19.1	25.2	10.8	20	16.9
Jun	29.4	13.3	3	18.0	29.9	14.2	1	18.4	31.0	15.2	1	18.9	22.1	7.3	7	15.9
Jul	29.5	12.4	2	19.1	30.0	13.4	2	19.5	31.1	14.5	2	19.9	22.1	6.3	7	17.3
Aug	31.8	13.9	0	21.7	32.2	15.1	1	21.9	33.0	15.8	1	22.0	25.0	8.2	5	20.5
Sep	35.2	18.2	4	23.4	35.5	19.6	7	23.0	35.8	19.7	6	23.1	29.5	12.7	8	23.5
Oct	37.5	22.2	22	23.7	36.6	23.6	27	23.5	37.0	22.2	40	23.2	33.2	16.9	14	25.5
Nov	38.0	24.3	65	22.3	37.5	24.7	92	22.0	36.4	23.9	121	21.8	35.4	20.0	26	26.1
Dec	36.9	24.5	151	19.8	36.0	24.5	187	19.4	34.9	24.1	231	19.2	36.6	21.9	45	25.5

Chickpea yield and water requirement scenarios

Chickpea scenarios were developed using the same scheme as for peanuts. The scenarios for Ali Curung only (21°S) are presented in Figure 7.15. This indicated that up to 4 t/ha of chickpea could be harvested within 3 to 4 months of crop if up to 4 ML/ha of irrigation could be arranged.

7.5 Discussion

The APSIM model integrates our understanding of peanuts' physiology, agronomy, and genetics and the crop's interactions with the environment. One of the advantages of using APSIM is that major dynamic (weather) and static inputs (cultivar parameters with calibration, soil attributes) required can allow assessment of yield potential and potential risks, identify biophysical constraints including water and temperature and predict yield and phenology with a reasonable accuracy.

The peanut crop is underground, so visual assessment of pod yield and when to harvest is difficult compared to crops where maturity and the extent of grain set are visible. Therefore, predicting these parameters using weather variables using a simulation model becomes even more interesting for this crop. Even though pod maturity assessments based on pod mesocarp colour have been suggested, these are still not foolproof and involve some work to sample and rate maturity. Given that soil moisture influences peanut maturity, the assessment becomes even more difficult, especially in commercial-scale production. The data collected from various reports show that in both Douglas Daly and Katherine, peanuts were dug when they accumulated thermal time targets varying between 1700 °Cd to 2200 °Cd. This variation is substantial given that Florunner takes about 2000-degree days and Holt and Menzies take about 2100-degree days to mature. This variation is considerable, covering mid to full-season maturity as per the industry standards. A crop harvested early or later can underperform. However, data showed that the longer the thermal time target was allowed to accumulate, the lower the pod yields, as the pods formed early were lost. It is unknown if the maturity assessment using the crop model would have given a different recommendation of harvest time. We currently predict maturity using APSIM, particularly its decision support tool Aquaman, to make harvest decisions.

The observed pod yields in the range of 5 to 7 t/ha in NT environments indicate the crop's potential may be considered reasonable for broad acre cropping. However, these yields were not consistently realised. Apart from the issue related to harvest time, losses related to bird damage even in the standing crop, and foliar diseases, which are common in the wet season crop, were reported. Weeds could also be an issue that may be difficult to control in the wet season. However, our simulations suggest that a large part of this variation (up to 50% or more) could still be related to the environment, including soil water, solar radiation, and temperature.

Although APSIM slightly over predicted yield in most seasons/experiments, which is expected given it cannot simulate the losses due to biotic reasons and birds, its prediction was close to 50% accurate. The simulated yields were within one standard error of the observed pod yield data. The final pod yield and crop growth were also reasonably predicted. Some model parameters may need to be re-evaluated for the NT environment. For example, Hammer et al. (1995) indicated that harvest index, branching and leaf area development of peanuts could be affected by super optimum temperatures. There is also a possibility of temperature and soil water stress slowing down thermal time accumulation. For a practical farming situation, however, the accuracy achieved with one standard error in simulating independent data for the model may be acceptable, although higher accuracy may be desirable. We believe the accuracy would have been greater if we were to conduct these trials specifically for model validation.

There were uncertainties concerning maturity or dates and the amount of irrigation. In simulating these outputs, assumptions about soil physicochemical properties, including plant available water holding capacity, starting soil water, and starting moisture, were made. There was also uncertainty if the pod yields obtained were moisture corrected and assessed for maturity. Results of the trial involving two sowings to achieve this goal in the field may be helpful. Data from this trial could not be considered in assessing the model as relevant data were yet to be compiled. Further, the use of the APSIM next-generation model and its assessment in dedicated experiments, where the soil of the trial site is well characterised and agronomy details such as irrigation dates and dates of operations are well defined along local weather data, could further improve the accuracy of the model predictions.

At this stage, the scenarios generated as part of this project may rely upon the accuracy of the prediction model, which is about 50%. The extent of error in the estimates could be up to 21%. These scenarios indicated the yield potential of full-season cultivars up to 10t/ha in all environments tested. The pod yields realised from shorter season cultivars will be less. These are potential pod yields, and the actual pod yields always tend to be less due to difficulties in managing crops free from pests and diseases plus deficiency of all macro and micro nutrients (e.g. Zinc, Boron and Calcium), and yield losses during harvesting, which are currently not simulated by the model. Short-season and full-season cultivars have been recently re-parameterised and validated in Kingaroy environments and are hence worthy of some confidence in pod yield outcomes for the given weather data. Given irrigation was provided as an input to ensure minimum variation due to rainfall, pod yield variability was generally small except in some dry season sowings, which could have occurred due to frosts. There was high frost risk in some sowings on sites of southern latitudes (e.g. June sowing at Ali Curung). Such variation was most glaring at Ti Tree. In pod yield scenarios, three groups of locations can be surmised: more tropical areas such as Katherine, Douglas Daly, Larrimah, Tindal, and Tipperary, the second group of locations consisting of Ali Curung and Glen Arden and the third group was of Ti Tree. Differences in peanut yield between Ti Tree and Ali Curung – Glen Arden Group were surprising and required investigation, whether it was due to an issue with the met file or Ti Tree location is indeed different.

Similarly, scenarios for chickpeas production in the NT were promising. Australia is the second-largest producer of chickpea, but the crop has had decreased production in the southern states. Even in the traditional production regions in Asia, where chickpea is an important crop, it is increasingly being grown in more tropical environments. Hence, there is good scope to obtain tropically adapted cultivars from those countries for the NT. The potential expansion of chickpea as a broadacre crop in the NT could assist in maintaining chickpea supplies and the status of Australia as a significant chickpea producer.

7.6 Conclusions and recommendations

The work on model validation suggested that the APSIM model can simulate the pod yield of peanuts well. However, further validation work in dedicated experiments where soil characterisation can be done and the information on other inputs such as the amount irrigation and its dates are more precise will be required to improve the accuracy of prediction. In the absence of such data, the past data was mined from various reports for this project. Given that the APSIM model has been developed using data from a wide range of tropical areas, including Kununurra in WA and Jambegede in Indonesia, higher accuracy can be realised even in the NT environment. However, more work may be needed on the effect of temperature in the supra-optimal range and its impact, especially on the harvest index. It is likely high (>39°C) temperatures may be contributing to a substantial gap in the predicted and observed pod yields as the model may not be able to consider these effects adequately.

Irrigation management will be essential to realise high pod yields and lessen the effect of harsh temperatures; hence, having a reliable standby water supply will be necessary. In the past, irrigation decision support tools Exnut which works on temperature, have been tried in the NT. However, this irrigation decision support tool has had limited success. Aquaman is another decision support tool developed by the Department of Agriculture, Queensland (Chauhan et al. 2013) for irrigation management and predicting harvest times in peanuts, and is available from www.yieldprophet.com.au website. The program works on evapotranspiration demand computed by the APSIM model and could be tested to improve the efficiency of irrigation application in the NT environment.

Also, currently, the model does not simulate the effects of diseases which can be more severe in the wet season, which could be the source of potential inaccuracies in observed and predicted pod yields. Hence, there may be a need to model the effect of these diseases. A prototype model to simulate foliar diseases of peanuts has been developed but needs to be tested in the NT environment.

This pod yield scenario analysis suggested considerable scope for growing peanuts at eight locations in the NT. Pod yields of 5 to 10 t/ha were predicted in different sowing date cultivar combinations, and the model could be used to identify these combinations. Such pod yields should be achievable, at least in better-managed environments.

It will be interesting to verify these yield scenarios in the NT environment. Ideally, dates of sowing trials could be conducted at locations such as Katherine, Douglas Daly, and Ali Curung to verify yield outcomes further. If the yield gap is significant, reasons for the same should be identified. Further simulations for optimising Genotype x Environment x Management interactions and verifying them in the field are warranted.

Limited scenario work on chickpea also suggested that there is scope for introducing this crop in the NT. However, cultivars that could be grown in the tropical environment may need to be developed or introduced from elsewhere. These could be imported from India, where the chickpea revolution in the tropics occurred after tropically adapted chickpea cultivars (e.g., J-11) were bred and released to growers. However, more work on this crop may be rewarding given its propensity to grow on residual moisture in drier and warmer environments.

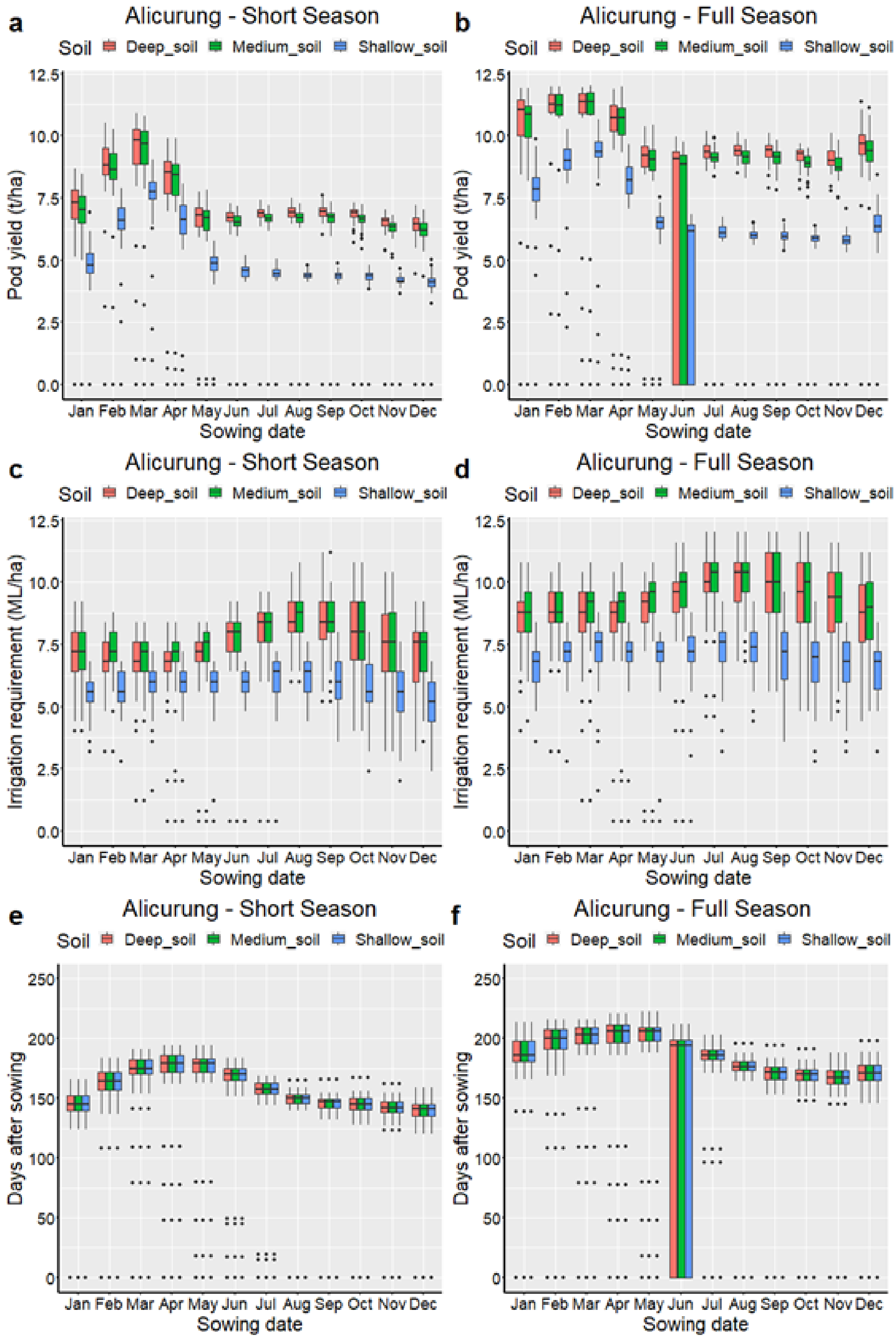

Fig. 7 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Ali Curung. The June sowing is most likely to fail in most years. Higher yields can be realised if the crop can be established between Januarys to March/April.

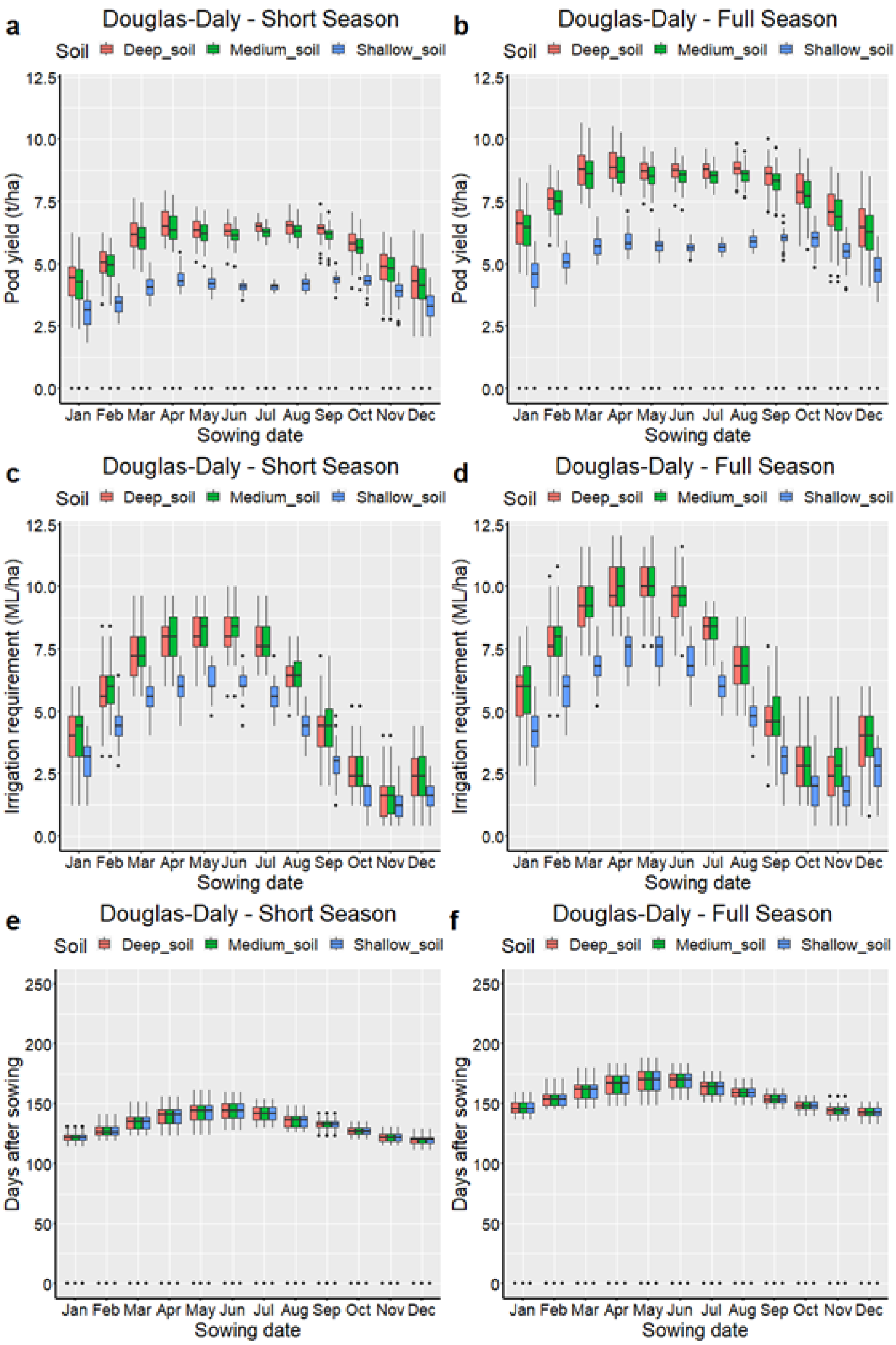

Fig. 8 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Douglas Daly.

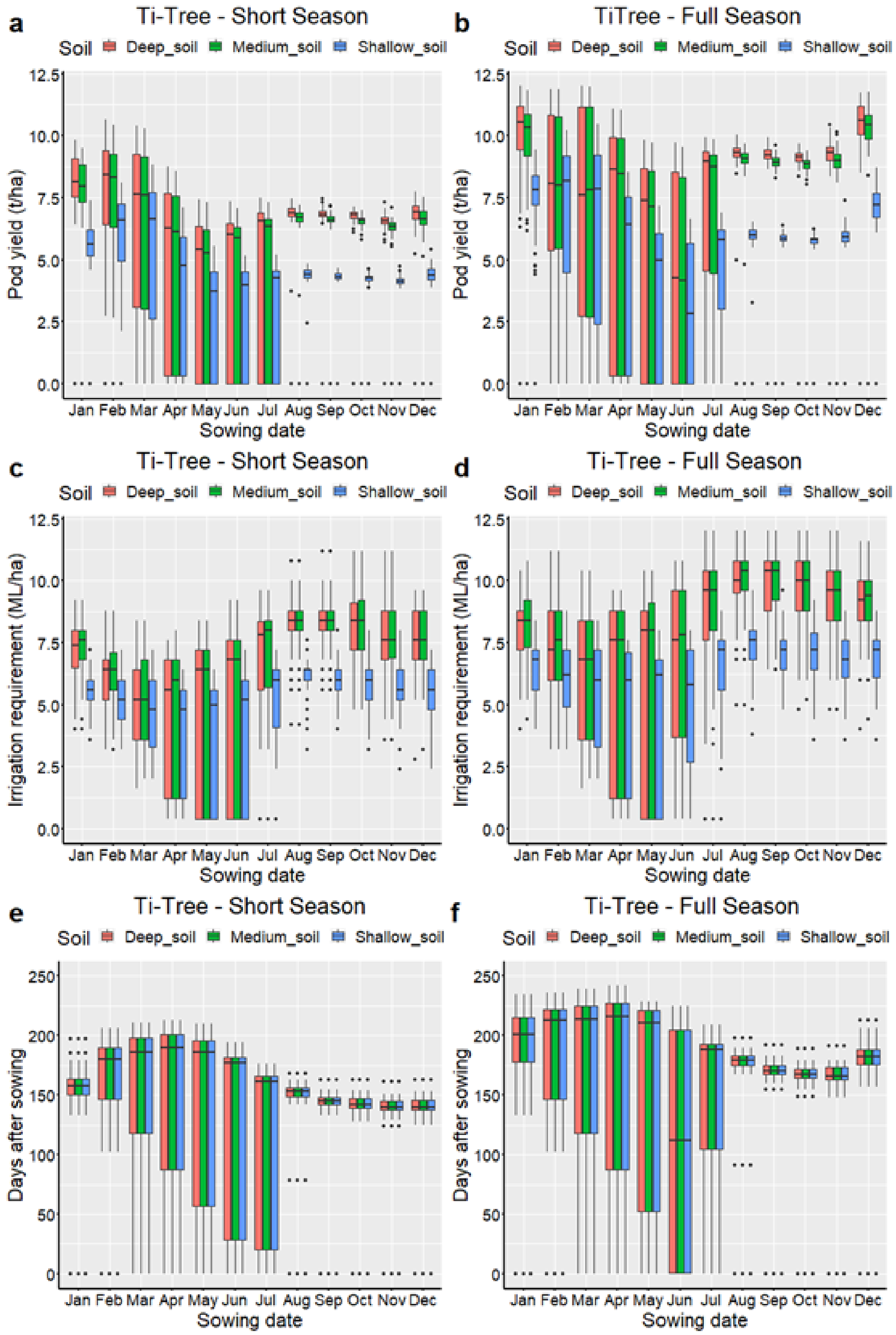

Fig. 9 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Ti Tree, NT.

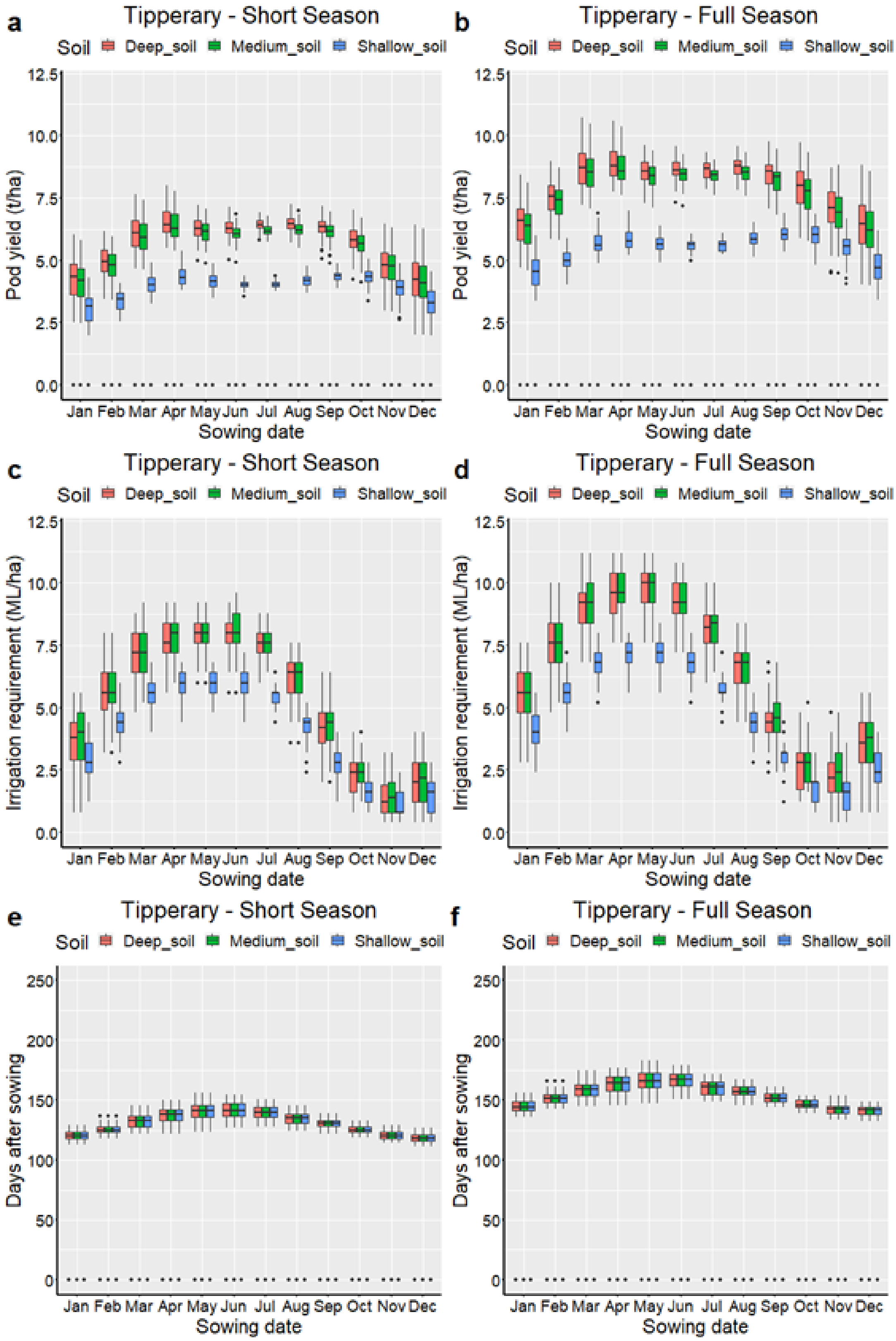

Fig.10 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Tipperary, NT.

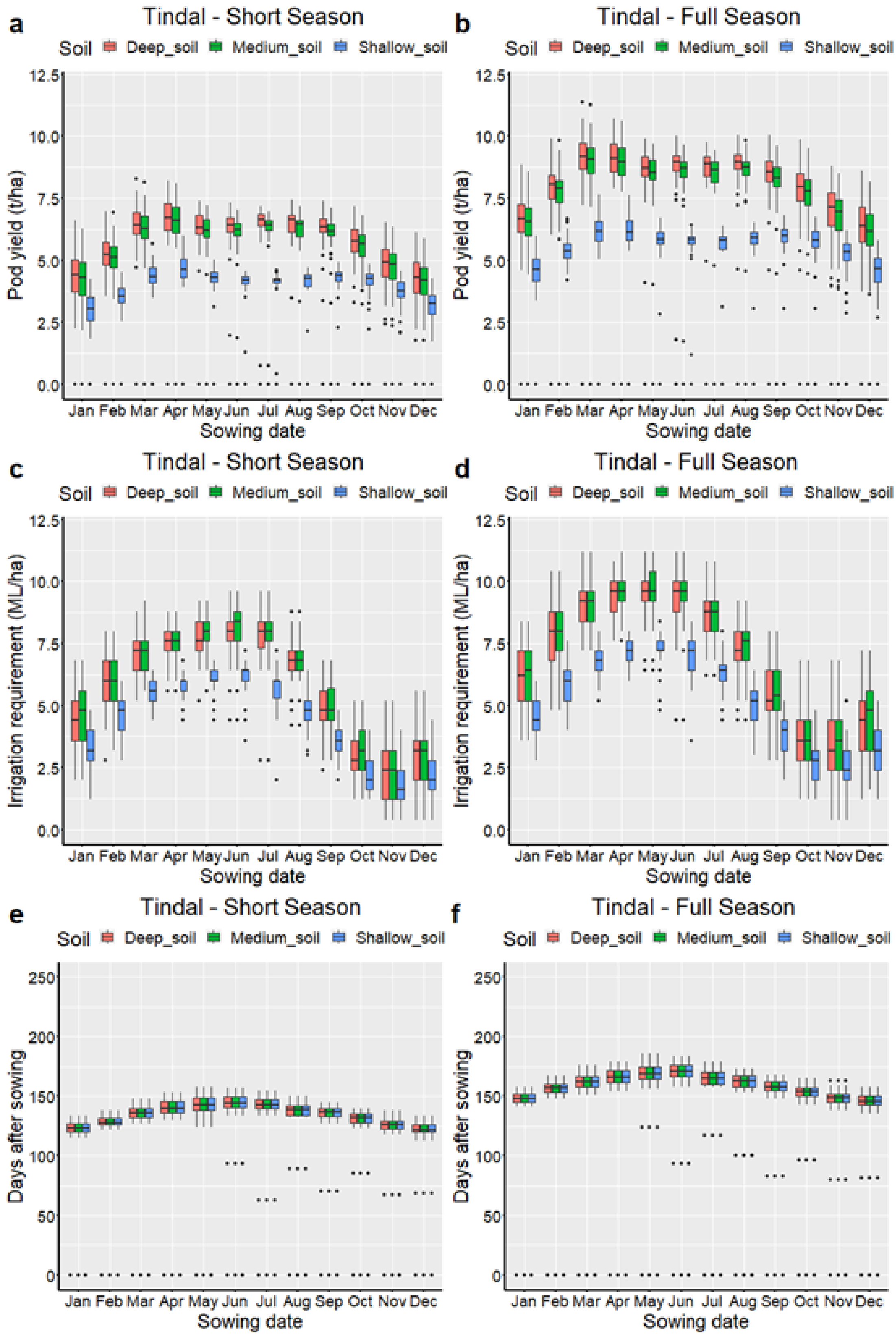

Fig.11 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Tindal, NT.

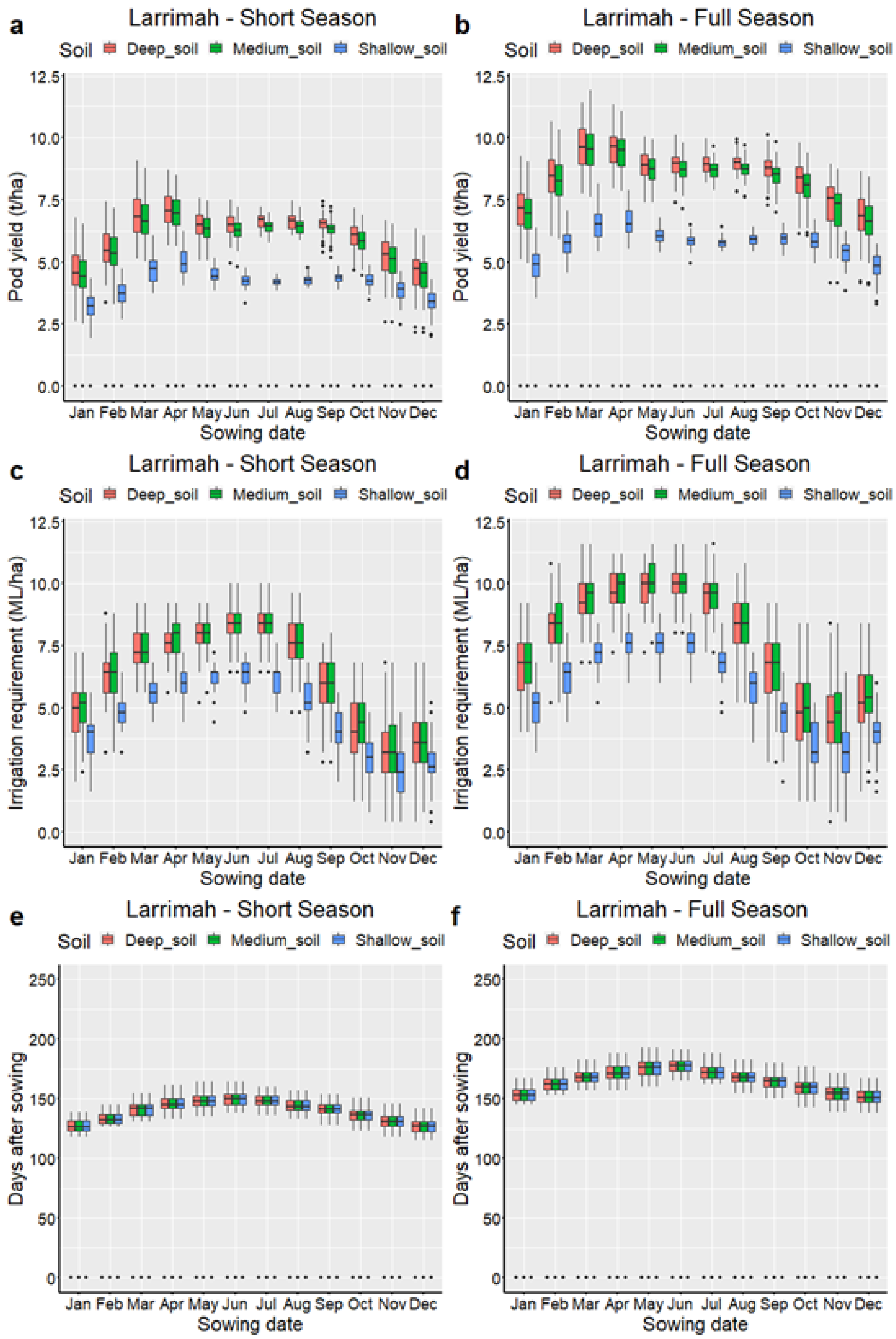

Fig. 12 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Larrimah, NT.

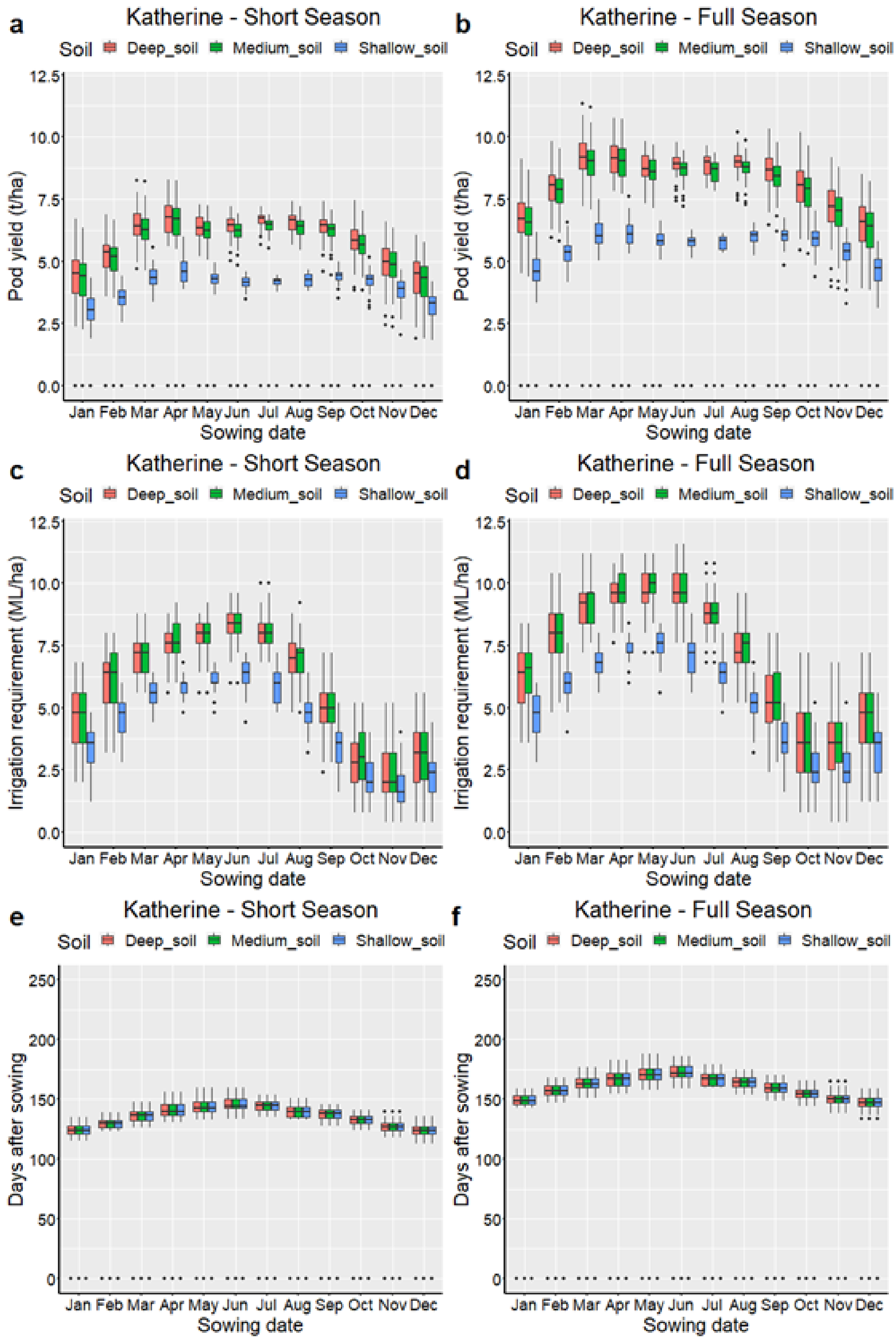

Fig. 13 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Katherine, NT.

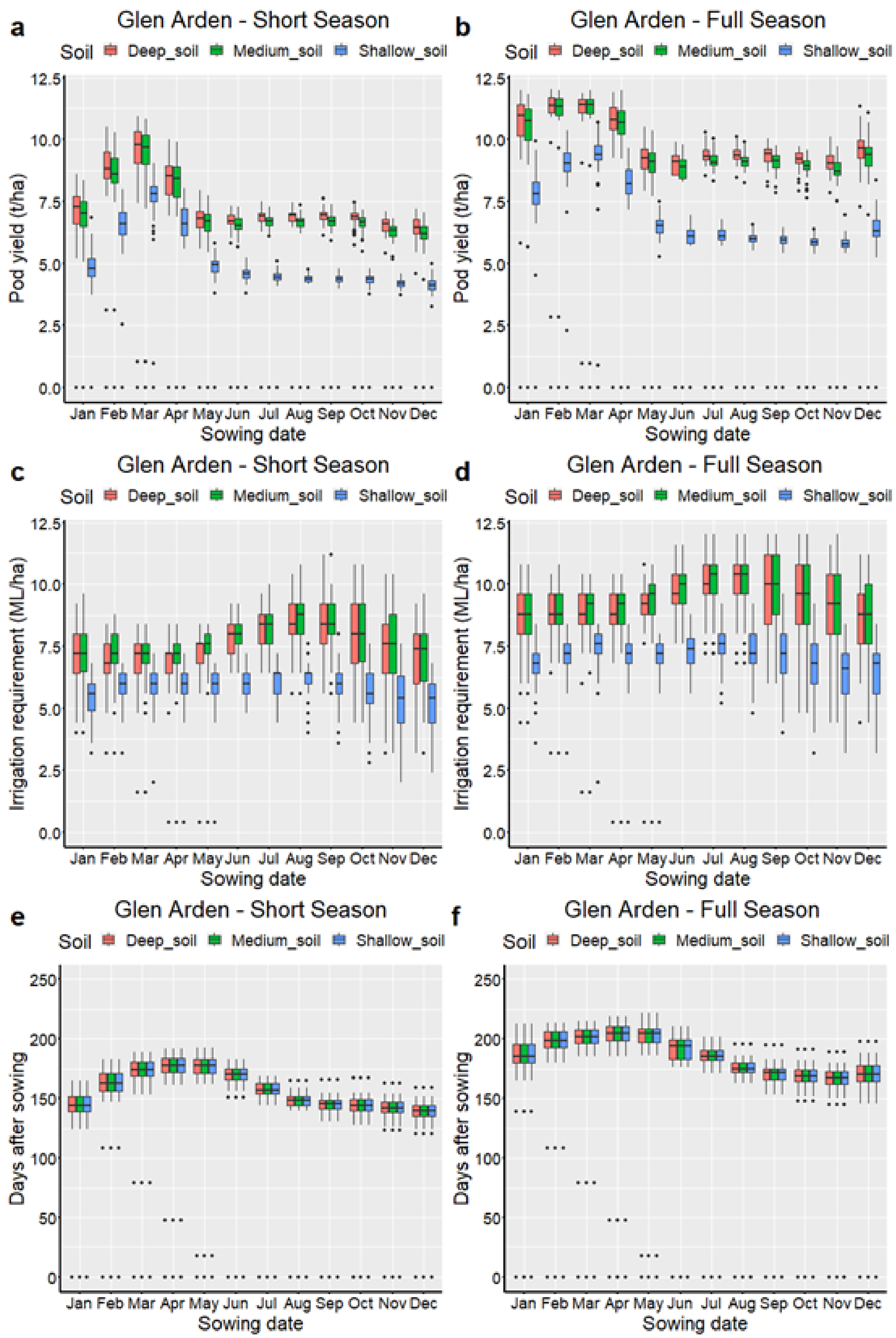

Fig. 14 Pod yield (a, b), irrigation requirement (c, d), and days after sowing (e, f) of short (a, c, e) and full-season peanuts (b, d, f) grown at Glen Arden, NT.

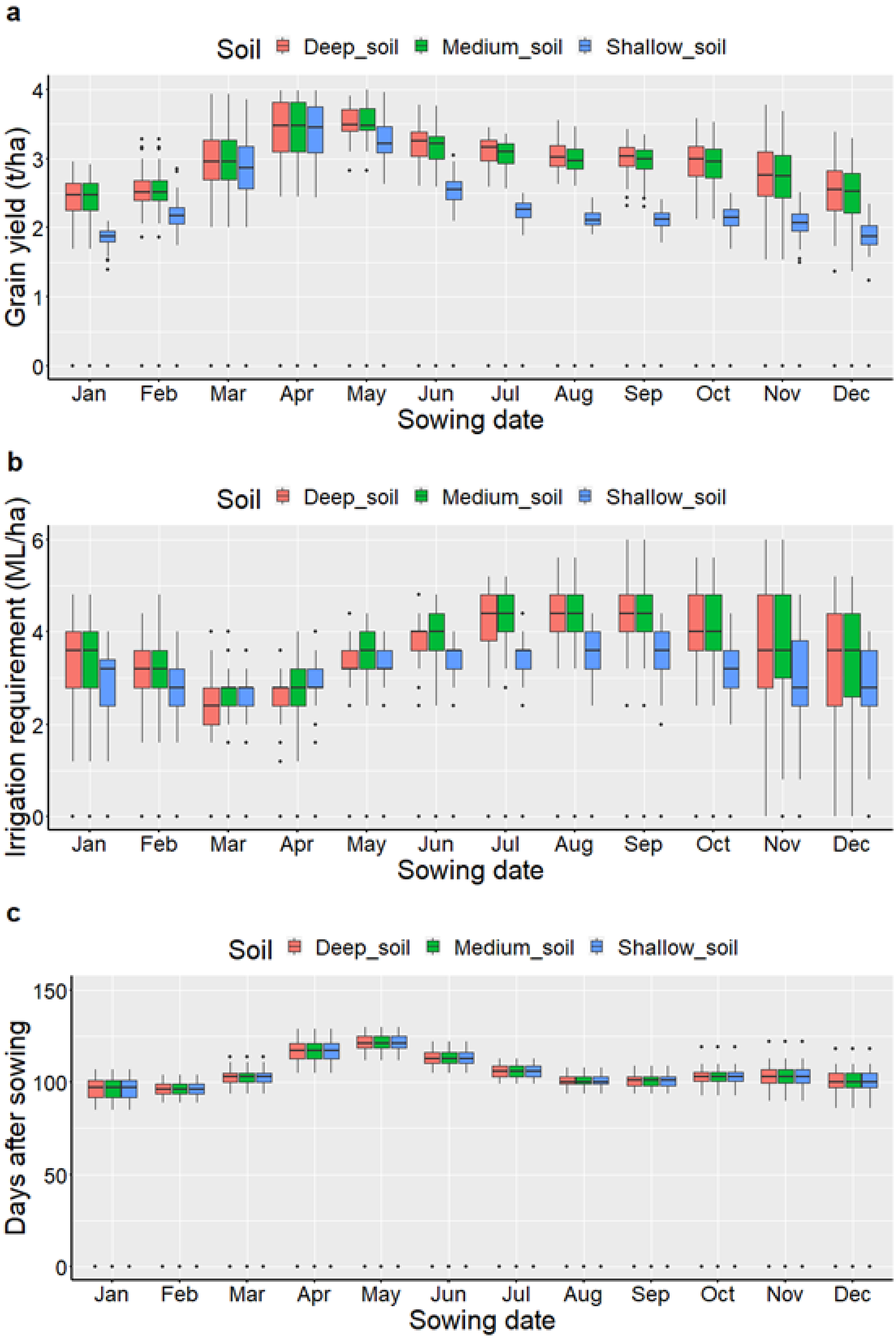

Fig. 15 Scenarios of chickpea production, water requirement and duration at Ali Curung

8. Industry Engagement and Capacity Building

8.1 Summary

NT Farmers, in collaboration with DITT and other relevant key stakeholders throughout the life of this project, provided opportunities for industry engagement and capacity building. NT Farmers coordinated and delivered four workshops/regional roadshows/conferences, and four field days were held throughout the life of this project. Moreover, NT Farmers also produced the 'Northern Australia Broadacre Cropping Manual' to benefit the industry stakeholders.

8.2 Activities completed by the project

Industry engagement capacity building activities completed by the project are listed below in chronological order:

1. A field day event in **June 2020** at Tipperary Group Station was held with over *60 key stakeholders* attending to look over 2019-2020 cotton plantings that at the time of the event were being picked. Attendees witnessed irrigated cotton being picked and listened to industry representatives discuss current findings in field.
2. A roadshow event held in Katherine in **September 2020** where over *105 delegates* attending a 2 ½ day event. The theme of this event was in line with the 2021 Food Futures Conference.
3. In **May 2021** NT Farmers hosted the Northern Australia Food Futures Conference in Darwin NT. Over *550 delegates* attended the 3-day event. The conference is integral in driving expansion in the north and places northern agriculture on the national agenda. Investors, politicians, industry and community stakeholders from around Australia and the world attend the conference to explore agricultural opportunities in the north.
4. *45 key stakeholders* attended a workshop in **November 2021** at the Douglas Daly Research Farm
5. **May 2022** a second regional roadshow event was held in Katherine to commence the promotion of the 2023 Northern Australia Food Futures Conference. The theme discussed 'Northern myths, realities & opportunities. *Over 120 delegates* attended the 1 ½ event and networking dinner.
6. **June 2022** completion of the Northern Broadacre Cropping Manual. A resource tool for northern growers who are currently or considering cropping in the north. The intention of the manual was to highlight the lesson learned to date on cropping systems with a wet season focus. This manual is a collaboration of work completed by several industry representatives. All those involved were acknowledged for their contributions and efforts.
7. **August 2022 – Cotton Conference Tour;** a grower group (10), including regional departmental officers was hosted to attend the biannual 3-day Australian Cotton Conference and Award Dinner. This is a national and international event that draws industry and growers together. The theme for this year's conference was 'Here For Good'. Significant recognition was given to the developments of the northern industry. Those northern growers who attended found the event was an extremely rewarding and valuable experience and regarded the networking opportunities highly. Tipperary

Group was awarded and acknowledged for their high achievements for the industry to date.

8. **Ongoing -** Regular quarterly NT Farmers GrowNT magazine publications identified and charted the status of the project and gave insight into the value of further R, D&E about this context for the NT.
9. **Ongoing** – grass roots discussion with NT Farmers members and other key stakeholders regarding property developments, diversification and cropping farming systems continues across several regions of the NT.

Some activities were captured and presented in photo collegial (Fig. 8.1).

Fig. 8 1 Photo collegial of industry engagement activities.

8.3 Key Outputs

NT Farmers was also responsible for the support and assistance with cropping trials completed on farm in central Australia and Douglas Daly over the 2020/2021 season. All planned requirements and expectations were met by NT Farmers.

8.4 Future Recommendations:

- Consistent project delivery and support to project participants to avoid drop out of the trial sites across the life of the project.
- Direct engagement with the project participants to develop and execute the project plans.
- Further work on other rotational cropping systems needs to be addressed, project became very cotton centric - Northern Australia Broadacre Cropping Manual' identified this gap.
- Broadacre cropping manual to be revised and updated to include crop variety trials (seasame/hemp/others) as required and work completed.
- Source further funding opportunities to provide legacy and value add to work completed.
- On-farm commercial trials needed to further explore to support key stakeholders and to improve relationships at a grass root level.

9. Conclusion

Potential for broadacre cropping in the NT project has played an important role in unifying the NT based cotton industry and bridging some of the important practice gaps by conducting targeted research and production knowledge outputs.

Field trials conducted on research and commercial farms have identified direction to find solutions of some of the complex dryland cotton and grain farming questions. Nevertheless, more questions have been identified for conducting future research. Management option scenarios included rain-fed dryland and irrigated, crop rotations, and sowing time. APSIM's predictive strength was employed for validation crops (both small plot & commercial) in different climatic conditions. Due to short time frames, Covid-19 restrictions, and limited resources, not all simulated crops were validated.

The APSIM modelled output provided an initial indication of the potential and extent of possible broadacre agriculture across the NT. This information will help to direct future agricultural RD&E in the NT. Since the crop simulations allow for virtual cropping over numerous years the impact of the highly variable NT weather on year to year viability of cropping was assessed. This allowed for an economic analysis to be completed to understand the financial implications for investing in this form of agriculture. Further, this assisted planners to understand the infrastructure required to support this potential cropping industry. The APSIM analysis was captured and made broadly available by adapting proven online tools (CropARM) as a resource to allow stakeholders to assess cropping options in the NT. Finally, this virtual cropping highlighted issues and knowledge gaps that required traditional research to answer, hence overcoming a shortage of learned experience regarding broadacre cropping in the NT. The advantage of completing the simulations first was that the sites and questions to be answered can be more targeted.

Crops that were investigated via crop simulation techniques included cotton, peanuts, maize, sorghum, rice, and pulses. The range of crops simulated included some that were not economically viable on a commercial farm. This allowed these crops to either be included in future projects for further understanding their potential or to be excluded from future studies.

To sum up, improving productivity and profitability of the NT cropping system is crucial for sustainable growth of the Territory's agriculture sector. An abundance of land suitable for producing high-value broadacre crops across central and northern Australia is available. However, growers and investors seek scientifically sound recommendations for selection of crops for the dryland farming systems. The research and development outputs of CRCNA funded 'Potential for broadacre cropping in the NT' and major infrastructure developments are supportive of establishing a self-sustained cotton industry in the NT. However, knowledge gaps in crop establishment, agronomy, biosecurity, technical skills, and an in-depth understanding of the social aspects associated with barriers to growth of broadacre cropping in the NT need to be adequately addressed. Building on the current needs of the NT cotton industry, the research initiated in 'Potential for broadacre cropping in the NT' project needs continuity with a clear commercial focus. The future research should be conducted collaboratively with the local dryland cotton and broadacre grains growers to address their immediate commercial priorities.

10. Recommendations

Building on recent research investment of CRCNA on 'Potential for broadacre cropping in the NT' project and aligned with the current needs of the NT cotton industry, a follow-up project may be developed and implemented collaboratively with the local dryland cotton and broadacre grains growers to address the following priorities.

1. Investigate solutions to unreliable cotton establishment via a structured and integrated research, development and engagement program developed in consultation with growers, providing more than solutions to the known causes in other crops (high soil temperatures, rapid soil drying and surface crusting) usually due to insufficient soil cover.
2. Understand the impact of various crop rotation combinations on productivity of cotton via evaluation of options with growers. This may include pre and post crop management, on-ground plant cover and species impact.
3. Optimise nutrition in terms of quantity and time of application of major and minor elements and exploring alternative nutrient options.
4. Investigate biosecurity risks associated with cotton and grain rotation system. This can be achieved by monitoring and managing the biological threats by ensuring locally adapted integrated pest management techniques are available and adopted.
5. Map and characterise the soil water availability for developing the enhanced cotton growth model. The enhanced cotton growth model can be applied on the most 'suitable' soils to assess regional yield and input variability, and identify better regions / locations for sustainable cotton production in the region.
6. Determine social acceptance and soil and landscape suitability for the NT Aboriginal titled land.
7. Assess application of an economic decision support tool to aid growers' decision making regarding the type of crops that are viable to develop economically efficient and ecologically sustainable farming systems.
8. Review the alignment of a range of potential cropping systems within the Territory's environment and regulatory frameworks.

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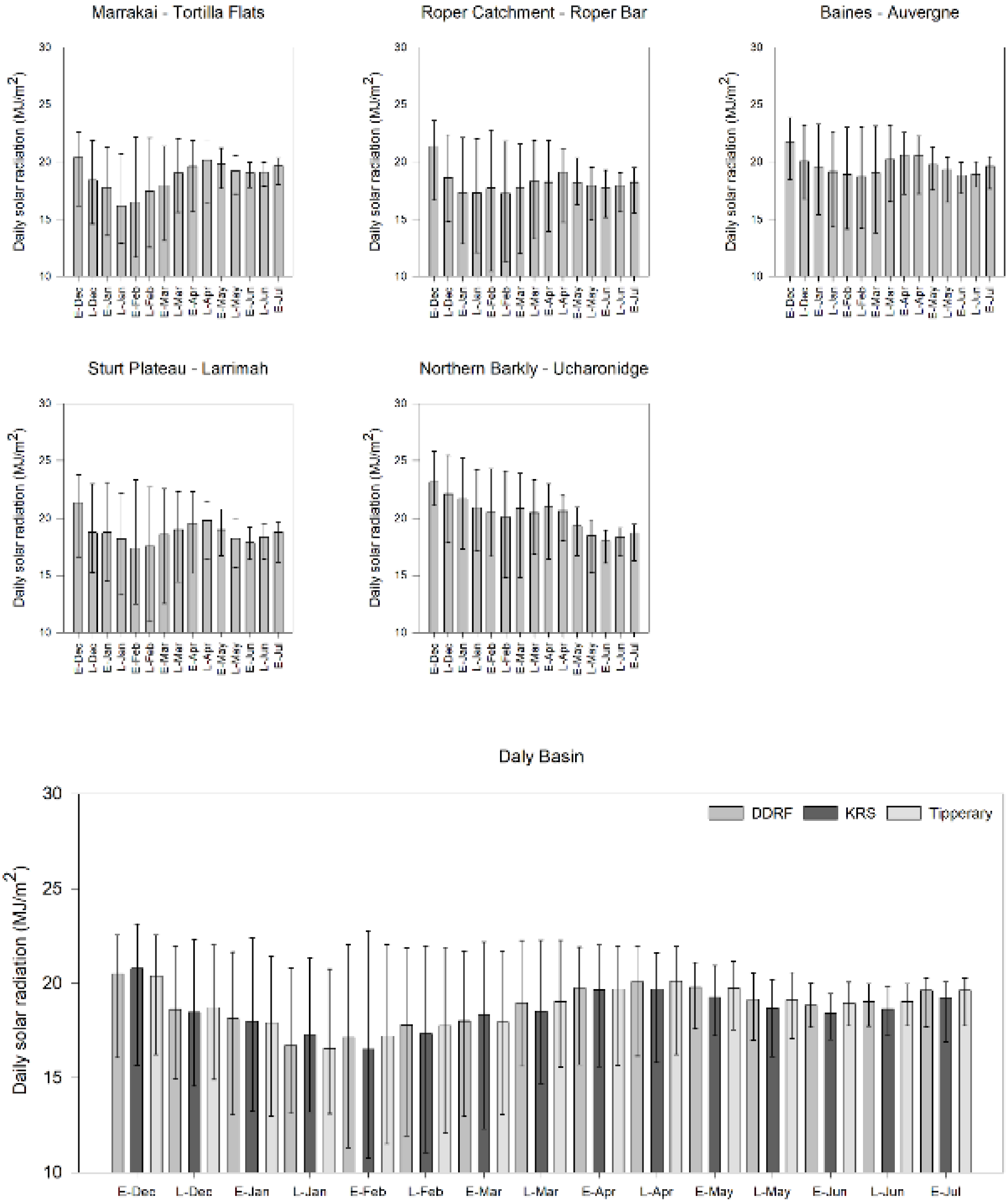
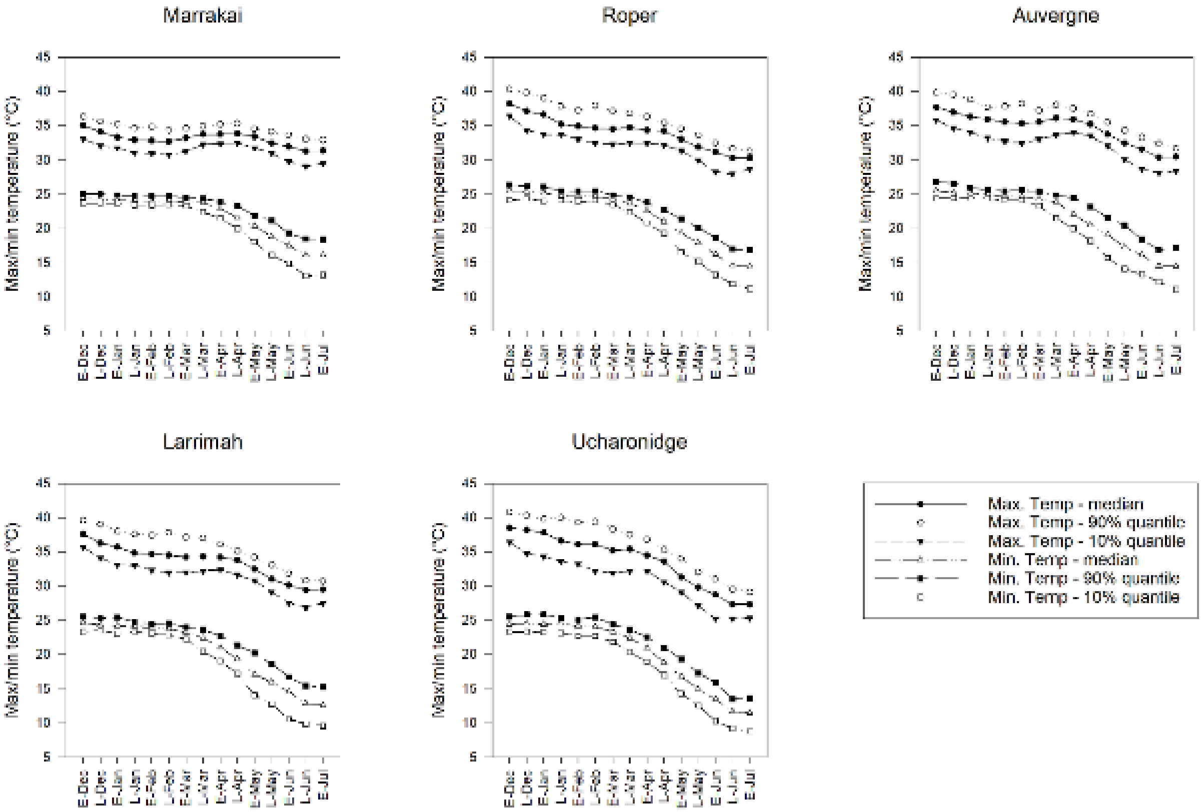
Appendices

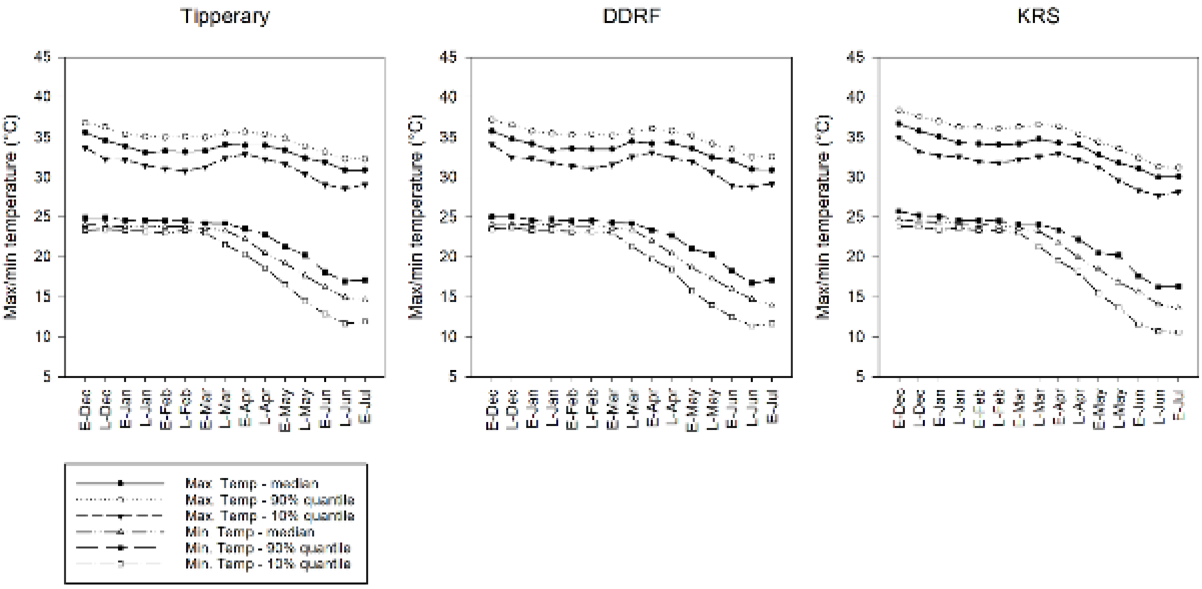
Appendix 2A. Half-monthly daily solar radiation for several potential cotton growing sites in the Northern Territory. Column bars show the median (50% of seasons) and error bars 10 to 90% of seasons (1957–2021).



Appendix 2B1. Half-monthly maximum and minimum temperatures for several potential cotton growing sites in the Northern Territory.

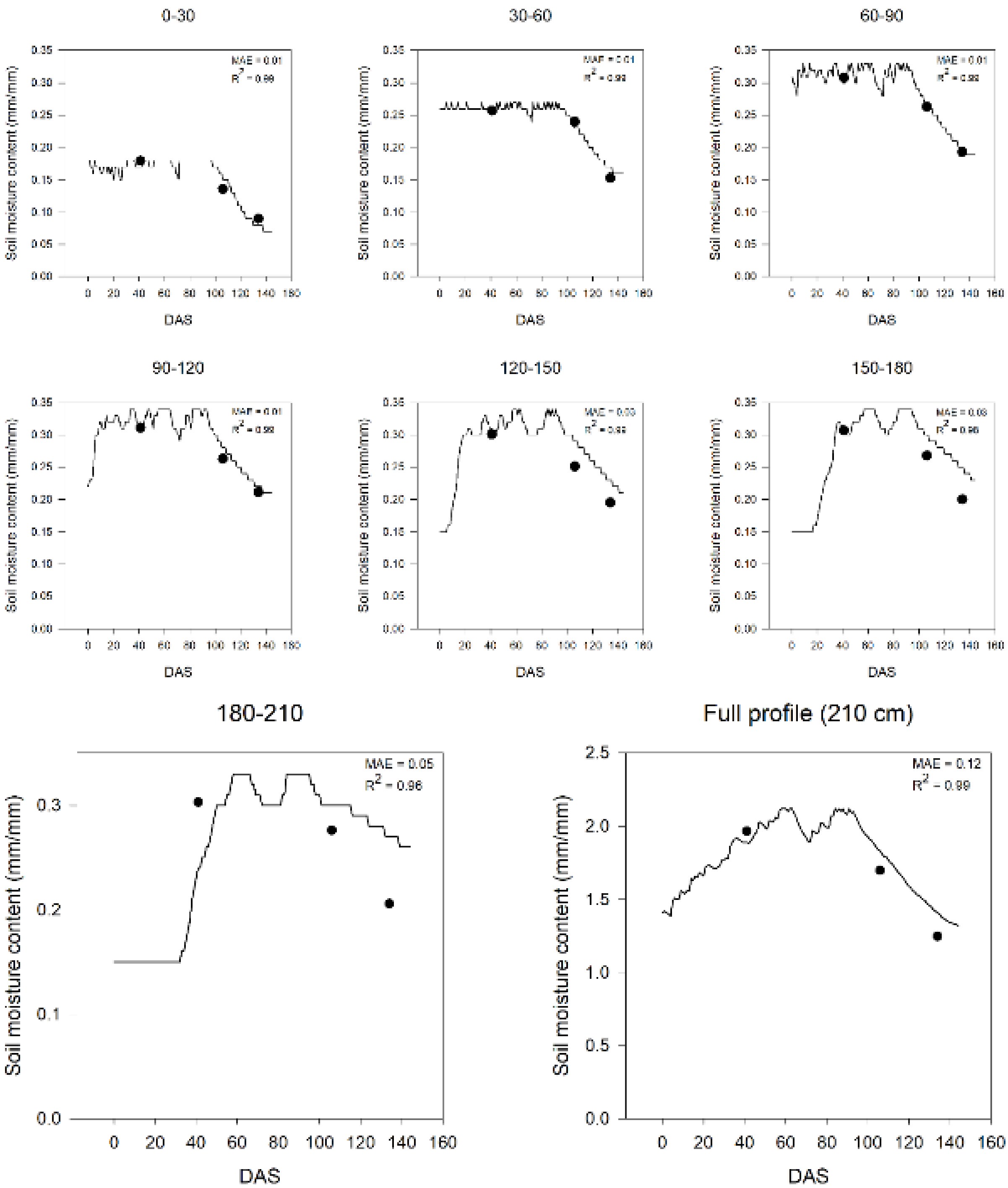


Appendix 2B2. Half-monthly maximum and minimum temperatures for several potential cotton growing sites in the Daly Basin, Northern Territory.

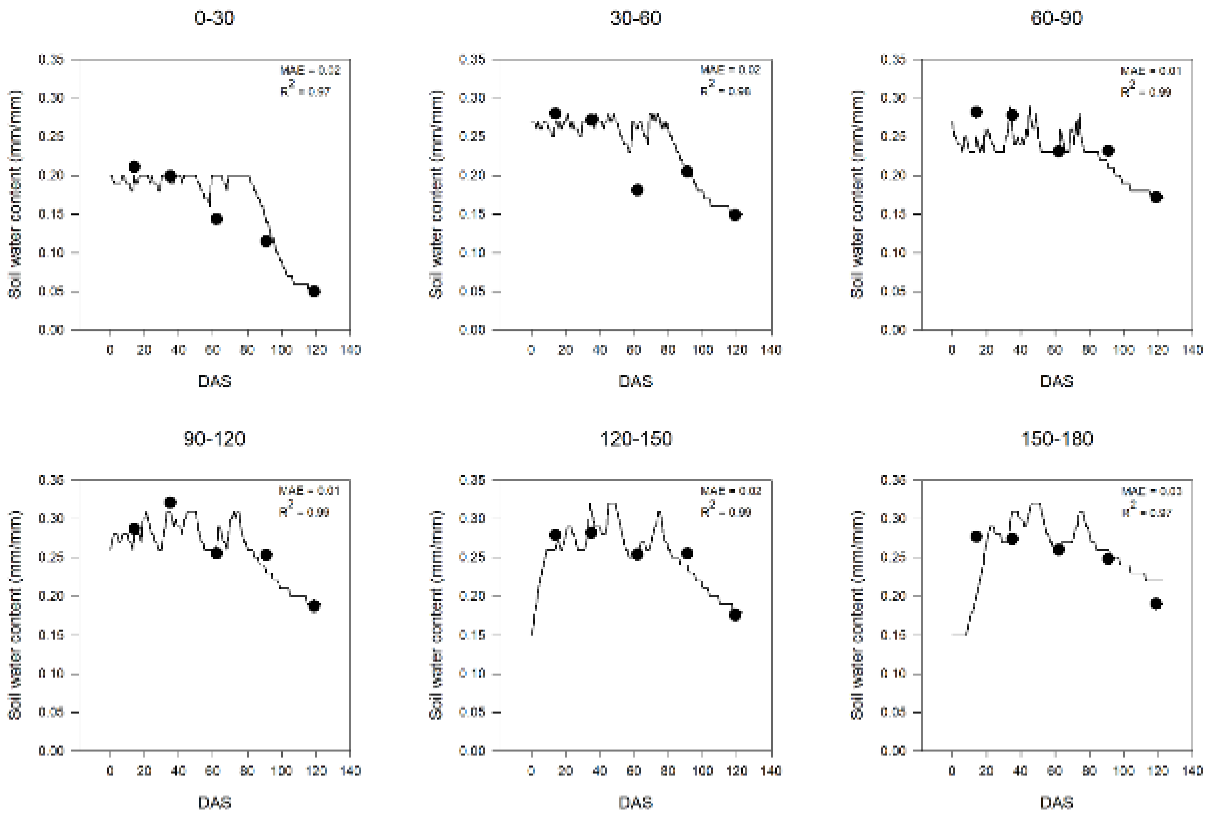


Appendix 2C. Comparison of simulated and observed values of soil water content at different soil depths for three Oolloo soils at Douglas Daly.

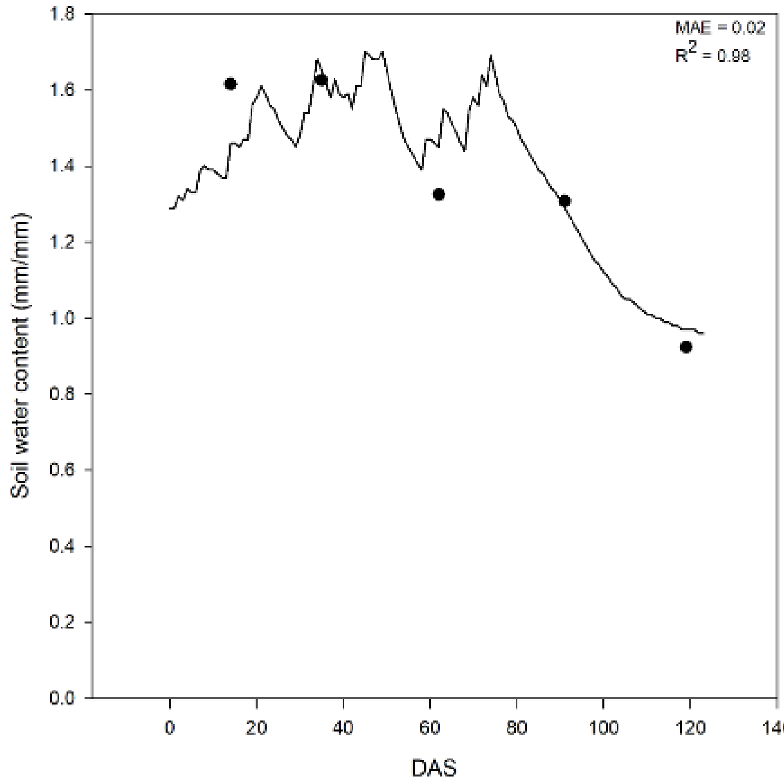
McBean 2021:



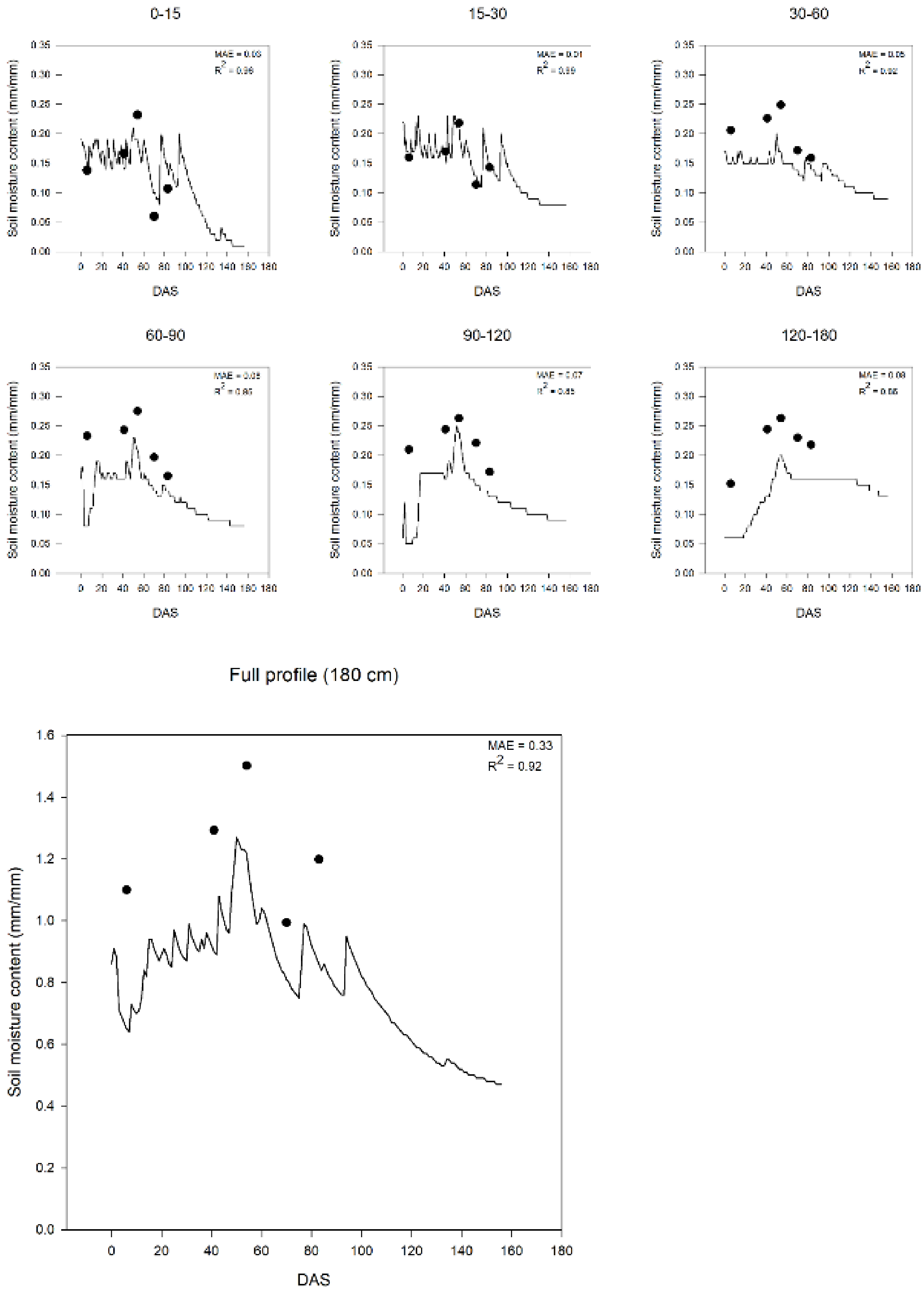
Douglas Daly Research Farm 2021:



Full profile (180 cm)



Howie 2020:

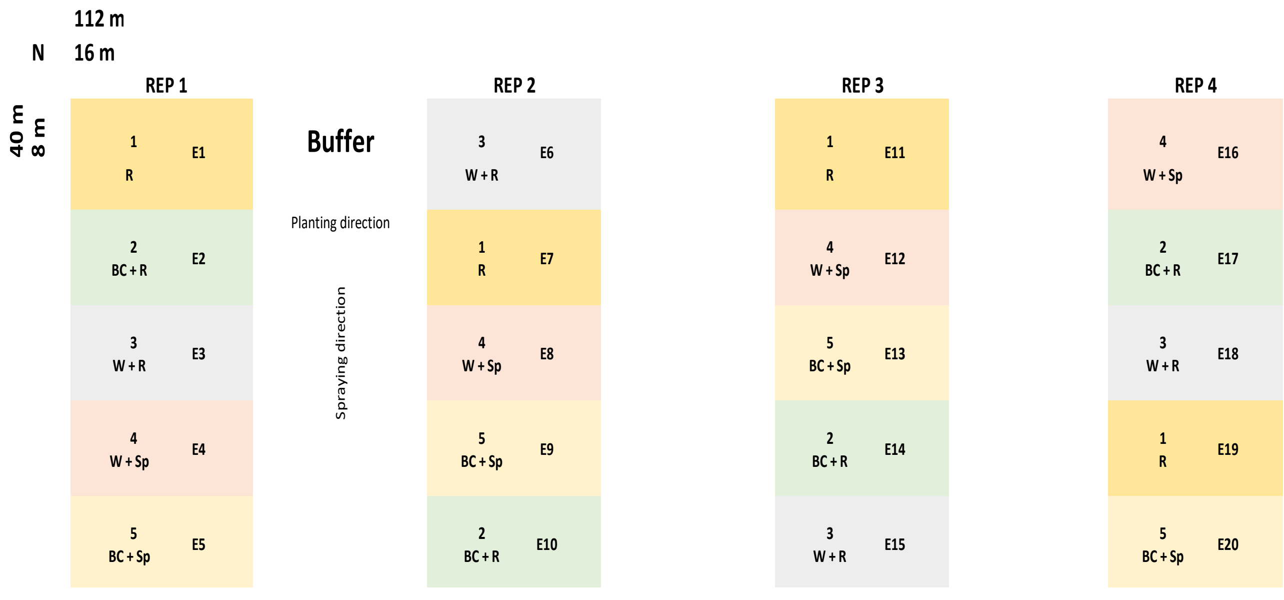

0-15
15-30
30-60
60-90
90-120
120-180
Soil moisture content (mm/mm)
DAS
Full profile (180 cm)
MAE = 0.33
R^2 = 0.92
Soil moisture content (mm/mm)
DAS

Appendix 5A Applied chemicals and fertilizers of the 2 planting establishment trials

Establishment #1	17/12/2021	Fertilizer		12-5-14-14 + te (B.02, MgO 2, Zn .01)	450 kg/ha
Establishment #1	18/12/2021	Planting	Seed	SC748B3F	
Establishment #1	19/12/2021	spraying	Panzer 540	Knock down spray	3 lit/ha
Establishment #1	19/12/2021	spraying	Chlorpyrifos	Insecticide	1.1 lit/ha
Establishment #2	6/01/2022	Fertilizer		12-5-14-14 + te (B.02, MgO 2, Zn .01)	450 kg/ha
Establishment #2	6/01/2022	Planting	Seed	SC748B3F	11 seeds per meter
Establishment #1 + #2	7/02/2022	Fertilizer	Urea	Urea	100 kg/ha
Establishment #1 + #2	26/01/2022	spraying	Panzer 540	weed control	3 lit/ha
Establishment #1 + #2	8/03/2022	spraying	Panzer 540	weed control	1.9 lit/ha
Establishment #1 + #2	10/03/2022	spraying	Mepiquat 38	Growth regulant	0.4 lit/ha
Establishment #1 + #2	27/05/2022	spraying	Promote	Growth regulant	1.5 lit/ha
Establishment #1 + #2	27/05/2022	spraying	Esculate	Growth regulant	.15 lit/ha
Establishment #1 + #2	16/05/2022	Plots hand harvest			

Appendix 5B Field plan

Treat
1 R: control - only rubber, no coulter:
2 BC + R: bubble coulter + rubber
3 W + R: wave coulter + rubber
4 W + Sp: wave coulter + spikes
5 BC + Sp: bubble coulter + spikes



PADDOCK 57A

NB:Trial design and treatment layout was the same for each establishment planting.