FINAL REPORT

CRDC ID: CSP1903

Project Title: Science Leadership for cotton in northern Australia

Confidential or for public release? Yes

Recognition of support: The Research Provider CSIRO acknowledges the financial assistance of the Cotton Research and Development Corporation and the partnerships with CRCNA, NTDITT and NTDEW? in order to undertake this project.

Part 1 – Contact Details & Submission Checklist

Principal Researcher: Dr Stephen Yeates, Principal Research Scientist
Organisation: CSIRO
Ph: 0747538588
E-mail: stephen.yeates@csiro.au

Supervisor: AS above
Organisation:
Ph:
E-mail:

Researcher 2: Dr Tiemen Rhebergen, Post Doctorial Fellow
Organisation: CSIRO
Ph:
E-mail: tiemen.rhebergen@csiro.au

Submission checklist.
Please ensure all documentation has been completed and included with this final report:
☒ Final report template (this document)
☒ Final Technical Report
☐ Final Schedule 2: IP register
☐ Final Schedule 3: Acknowledgment
☐ Final financial report
☐ PDF of all journal articles (for CRDC's records)

Signature of Research Provider Representative: 

Date submitted: 14/12/2022

Part 2 - Monitoring & Evaluation

This data is for CRDC's internal M&E requirements. Please complete all fields and add additional rows into each table if required.

Achievement against milestones in the Full Research Proposal

Milestone	Achieved/ Partially Achieved/ Not Achieved	Explanation
1.1. Contribution to cotton component of CRC-NA project "Potential for broadacre cropping in the NT" *1.2.* Implementation of Local BMP	Achieved Achieved	Meet project milestones, reports are in Part 3 See Part 3 and progress reports
2.1 Are the best soils for dryland cotton viable 2.2 What new local management is required	Partially Achieved Achieved	Due CSIRO scientists filling in for NTDITT professionals between resignation and replacement (15 months) model calibration and validation took longer than planned. Got to the stage of modelling yield response to soil type, see "Modelling Report" in Part 3. Modelling analysis found carrying over soil cover from the previous wet season (e.g. sorghum or forage grasses) is required to reduce the risk of not planting due to insufficient soils cover in drier regions (Katherine & south). See Part 3
3.1 Can a locally tailored OZCOT-APSIM simulate, yields (dryland and irrigated), colour grade, water use and growing season length? 3.2 Can soil trafficability be predicted to assess operational risk during the wet season?	Partially Achieved Partially Achieved	Unsuccessful for irrigated cotton. There were no weather events to down grade colour during the project so couldn't be modelled. Yes, for soils and management in modelling analysis (Part 3). No opportunity to test other soils or management.
4. General Biosecurity Issues	Achieved	Paul Grundy addressed this, see progress reports and his reports.
5.1 Extension of past cotton R&D – locally tailored information 5.2 Local production skill development. 5.3. Science Skills	Achieved	All milestones were key project activities – see Part 3. More difficult than planned due to COVID-19 travel restrictions.

Outputs produced *(Please refer to examples document to assist in completing this section).*

Output	Description
Reports	4 field and modelling research activity reports (Part 3)
Publications	5 listed in (part 3) all were related to support for new growers and researchers.
Presentations and provision of support information	There were many, these are listed in Part 3

Outcomes from project outputs *(Refer to examples document).*

Outcome	Description
Increased knowledge on zero-tillage in to mulch cover and local soils	Local workshop and presentations at reviews and grower meetings (see part 3)
Increased knowledge of tropical climate's impact on cotton growth and the management required to address these changes	*Local workshops, field walks and presentations*

Part 3 – Technical Report

Executive Summary

The title of this project "Science leadership for cotton development in Northern Australia" required technical support for new cotton industries across a huge (1/3 of Australia) new and different region, climatically, biologically and culturally. As anyone associated with cotton in Australia knows since the end of 2019 investment and test farming of cotton in the tropical north was massive. To be efficient and effective in this environment with a small team this project has minimised overlap with other cotton projects, delivered resources and information collated from past northern cotton and relevant other broad acre crop R&D, entered into partnerships with local agencies / farmer groups e.g. CRCNA collaboration in the NT. Flexibility to address new issues was required e.g. the partnership with Vanderfield, CSD and the CRCNA project to address establishment challenges with rain grown cotton. From the onset assisting local technical skill development was a key activity, this encompassed research, crop monitoring and crop management and natural resources (suitable soils).

1. <u>Delivery of resources and past information</u>

Two industry publications were written in late 2019 early 2020 and distributed and supported by workshops during 2020, the 'Northern Newsletter' and one to one (information support and publications section). The aim being to focus the wave of new growers on the known but unique challenges for growing wet season cotton, that is reliable crop establishment, planting date, suitable soils, nitrogen, growth regulator and pest management. These activities were very effective for rain grow growers as the majority have attempted and persisted with zero tillage into uniform soil mulch cover with the knowledge farm level tailoring is required. Delivery of information and resources continued for the life of the project, although often hamstrung by COVID-19 restrictions.

2. <u>Field research</u>

Four activities are reported here. "NT rain grown cotton suitability, model calibration, validation and application" and "Monitoring of commercial cottonfields 2019/20 wet season" were planned from the onset. The "Cotton Row Spacing Comparisons 2020 & 2021 (rain grown) and " Maximising cotton seedling establishment in the Northern Territory 2021/2022" were in response to requests from growers and a serious problem for growers respectively.

<u>NT rain grown cotton suitability, model calibration validation and application</u>: Application of the locally validation OZCOT-APSIM model simulated cotton yields at 5 locations on 3 well drained cropping soils for 65 seasons. Key Findings: Locating soils with high availability of water to cotton is critical, the simulated yield loss of 14 to 26% for the soils with lower PAWC at Tipperary, Douglas Daly and Katherine is undesirable. Timely planting significantly increased median yield, with yield penalties of 17 to 40% for late planting (≥ 15 Jan) at all sites and soils. Sufficient mulch cover at planting to prevent drying of the seed slot, high soil temperatures and crusting was critical to crop establishment.

<u>Monitoring of commercial cotton fields:</u> 3 rain-grown and 3 irrigated cotton fields were monitored in the Douglas Daly – Tipperary region. Root penetration was very deep in Oolloo soils 230 to 300 cm and 180 to 240 cm in Tippera soils. Applying a significant proportion of N fertiliser in-crop by mid flowering was a successful strategy as there was no evidence in any field of soil nitrate accumulation below 150 to 210 cm due to the deep roots. Data from these sites was used for model validation and soil characterization.

<u>Rain grown row spacing comparisons:</u> When sown later, 7 and 25 January ,there was no yield benefit from rows wider than 1m. While 0.5 m rows matured 14 and 10 days earlier the small yield increase and weed suppression in 2022 is unlikely to justify the additional cost of stripper picking.

<u>Maximising Cotton Seedling Establishment 2022:</u> A preliminary comparison of 5 planter configurations sown into recently sprayed vs killed soil cover confirmed the need future focus on mulch cover x planter set up x climate/soil scenarios.

Research Reports

1. CRDC project only

Final Results Report for CRDC project CSP1903 "Science leadership for cotton development in Northern Australia'

NT rain grown cotton suitability: model calibration, validation and application.

Prepared by: Stephen Yeates & Tiemen Rhebergen CSIRO
Project Team: CSIRO: Neil Huth, Perry Poulton, Jenny Stanford
NT-DITT: Nick Hartley, Peter Shotton, Cameron Crawford
NT-DEPWS: Jason Hill

SUMMARY / KEY FINDINGS:

Background / Aim: Rain grown cotton in the NT had not been grown since the 1960's. To build an understanding short and long term production and risks, identify key management practices, and fine tune identification of suitable soil resources, the APSIM-OZCOT model needed to be locally validated and applied.

Methods: The OZCOT-APSIM model was calibrated and validated for rain grown cotton on local Kandosol soils using crop and soil data collected by this CRDC and partner CRCNA project. Cotton yield was simulated for 62 seasons to evaluate sowing date, available soil water and frequency of planting scenarios at 5 locations on 3 soils within the Daly Basin, Sturt plateau and Roper Catchment.

Key Findings:

- Recalibration of parameters to account for tropical successfully predicted lint yield, leaf area and soil water extraction when validated with independent data.
- For all regions, when planted 15 Dec to 15 Jan, the range of median lint yields (50% of seasons) was 5.5 to 2.9 b/ha with Tipperary & Douglas Daly > Katherine, > Ngukurr & Larrimah, and Blain ≥ Oolloo > Tippera soils. Reflecting seasonal rainfall and plant available soil water at each region. Importantly for all locations and soil types, the between seasonal range in median yields were very large (± 95% to 130%).
- In the short to medium term, locating soils with high availability of water to cotton is critical to reliable and acceptable yield of rain grown cotton in the NT. The yield benefit of growing cotton on soils with greatest available water was strongly demonstrated at all locations and soils, particularly the Tippera soils. The median yield loss of 14 to 26% for the soils with lower PAWC at Tipperary, Douglas Daly and Katherine is undesirable.
- Timely planting significantly increase median yield, with yield penalties of 17 to 40% for late planting (≥ 15 Jan) at all sites and soils. Practices / technologies that can increase the chances of timely planting and maximise planting days will need to evolve during the early years of cotton industry development.
- At the higher rainfall locations, Tipperary and Douglas Daly, median yields were increased 9 to 24% by planting earlier (1 to 14 Dec), however crop establishment was only possible in 14 to 20 % of seasons. Lack of rainfall or insufficient soil cover at planting were the major causes for not planting. Early planting will increase the risk of pre picking rainfall discolouring cotton fibre in about 10% of seasons, as the majority of bolls are likely to open in late March – early April.
- For lower rainfall regions (Katherine and south) timely crop establishment was challenged by insufficient rain prior to planting to grow soil cover to protect seedlings from high soil temperatures, rapid drying of the planting slot and surface crusting. Cropping systems that carry over soil cover from the previous wet season (e.g. sorghum or forage grasses) are required to reduce this risk.
- An economic assessment that calculates long-term annual gross margins from simulated cotton yields produced from the farming system, is needed to determine the regional prospects for cotton, particularly for the lower yielding drier regions.

BACKGROUND

When this project commenced in October 2018, no cotton crops (research or commercial) had been grown in the NT since 2005. Following the approval to grow Bollgard 3 cotton varieties in 2017, interest in cotton was reactivated. By 2022 about 10,000 ha of cotton was planted in the NT the great majority rain grown in the higher rainfall Tipperary – Katherine Daly regions.

However, since 2018 nothing has changed with respect to the long known climatic, soil, biophysical and economic challenges to growing rain grown cotton and other broadacre crops in the NT. Historically, with the exception of forage crops, no rain grown (or irrigated) broadacre cropping (including cotton) in the NT has proven successful but interest in developing a profitable farming system for the NT remains.

The only significant previous research and test farming of rain grown cotton in the NT was between 1946 and 1964 by CSIRO and NT Agricultural Branch (Yeates 2001). The former concluded "*the economic prospects for dryland cotton in the Tipperary region are poor. On the other hand, on general hydrological grounds, groundwater reserves in areas of Tippera clay loam should be substantial"* (Norman 1966)*;* the later concluded *"the future for cotton growing in Australia lies in the large uniform irrigation areas – for example, the Namoi and the Ord"* (Mentz 1966).

The need to address these challenges and renewed interest in growing cotton, combined with technical and infrastructure advances since the 1960's instigated the work reported here.

The broad aims of the research reported here were to assess the natural resource potential (soil, water, climate) for cotton production systems and the cropping potential of possible production regions in the NT. Modern crop simulation programs like APSIM & OZCOT when locally validated are powerful tools can be applied to extend learnings from field research, build an understanding short and long term risk profiles, identify key management decisions, fine tune identification of suitable soil resources and incorporate grower experience while developing an overall picture of the cropping potential of a region. The long known within region heterogeneity of NT Kandosols (Williams et al 1985) provides both an opportunity and a challenge for this endeavour.

As stated in this CRDC project proposal "The project will support dryland cropping development via access to available northern R&D information and simple characterisation of possible soils for available water, infiltration conductivity and N availability then modelling analysis to identify soils most suited to dryland cotton". In addition, the previous research has demonstrated the need for a locally validated cotton model and cotton specific characterisation of local soils, particularly to account for the deep rooting (up to 3 m) observed in Kandosols which dominate the regions under investigation.

This report addresses the modelling validation and application component of project Milestones 2 & 3 with links to Milestone 1. It also contributed to the collaboration with CRC-NA project "Potential for broadacre cropping in the NT" without which essential soil resource and crop data could not have collected and applied. Although the greater capacity provided by this collaboration was so some extent negated by COVID-19 travel restrictions in 2020 within the NT and to intestate team members.

The OZCOT-APSIM model is not validated for cotton grown in the tropical wet season. Previous research in north Queensland and the Ord River WA identified the need for field research to recalibrate key OZCOT parameters due changes in crop morphology, rooting depth, crop development and fruit retention (Yeates unpublished, Grundy et al. 2020a,b, Yeates et al. 2010, Grundy et al. 2012, Yeates and Poulton 2019). Hence, calibration and validation of the model is an essential first step in assessing the potential for rain grown cotton in the NT.

REPORT STRUCTURE

This report will be in the three sections:

A. OZCOT – APSIM model calibration and validation, plant and soil.
B. Model application studies for rain gown cotton in the NT
C. Implications of model enhancements and application for NT cotton land suitability assessments.

A. APSIM-OZCOT model calibration and validation

Model description

The OZCOT cotton growth model can simulate the yield, fruiting dynamics and time-to-maturity of upland cotton (*Gossypium hirsutum* L.) in response to climate (temperature, rainfall, radiation) and management inputs (nitrogen, water, plant population, genotype). It has been calibrated and validated for spring sown cotton at temperate latitudes (e.g. Carberry and Bange, 1998; Hearn, 1994; Milroy et al., 2004) and irrigated dry season cotton in the tropics (Yeates and Bange 2003, Yeates and Martin 2006). The model is described in detail by Hearn (1994). Potential lint yield is simulated in the absence of disease, weed infestations and nutrient deficiencies other than N. It has a dynamic fruiting routine capable of integrating fruit initiation, growth and development with the plants carbon, water and nitrogen supply.

The agricultural production systems simulation model (APSIM) is linked to OZCOT, simulates production system scenarios involving a range of crops using a common soil module (Keating et al. 2003, McCown et al.1996; Probert et al. 1998). The APSIM soil module permits OZCOT to simulate cotton yield and water balance on a wide range of soil types and management options including mulches retained on the soil surface or incorporated, cover/rotation crops and N fertiliser management.

The predictive capacity of these simulation models is subject to the accuracy of the input data used as a basis for each simulation scenario. The key inputs required by APSIM are long-term daily climate records, characterized soils describing Plant Available Water Capacity (PAWC) and agronomic practice for managing irrigation and crop agronomy. The model simulates an achievable yield as it assumes best practice in nutrient, weed, insect and disease management.

The report by Yeates and Poulton (2019) "Determining dryland cotton yield potential in the NT: Preliminary climate assessment and yield simulation" (written for this project and included in this final CRDC report) applied an uncalibrated and unvalidated model. The study identified the soil resource and crop management were critical to higher, more reliable long term yields. There was a fivefold effect on yield due to a combination available soil water and crop management (planting date, mulch cover amount and type, nitrogen management). A calibrated and validated cotton model was required to follow-up these findings.

Methods

Calibration

The following data from the row spacing experiment at Douglas Daly Research Farm in 2021 (13.83°S, 131.21°E) was used to calibrate the models: Leaf area, maturity, lint yield, soil water g/g extraction, NO_3 and NH_4 by depth to 350 cm on 2 dates, to 240 cm on 6 dates, organic carbon to 30 cm, pre sowing much cover & N%. To be compatible with the model validation and commercial cropping practice, data from the 1 m row spacing was used. Soil parameters required for APSIM soil files, such bulk density, were collected by NT Department of Environment, Parks and Water Security (DEPWS) (more details in row spacing experiment report and Edmeades 2020 & 2021)

Validation

Six cotton crops (2 irrigated and 4 rain-grown) in the NT from 2019 to 2021 were used for APSIM-OZCOT validation, details below:

2019: Katherine Research Station, Tippera soil, rain grown. Data source: Biggs and Hartley (2019) "Cotton evaluation at Katherine research Station 2019", Internal report for NTDITT.

2020: Douglas Daly and Tipperary Station. Data source: Yeates et al. (2020), "Cotton Monitoring Reports" for CRDCNA & CRDC (report included). Fields (soil): A (Oolloo), C (Tippera), D (Oolloo) & E (Tippera).

2021: Crop monitoring of Billabong Field, "Ruby Downs", Douglas Daly: Three datum areas, cotton sown 24-Dec-20 zero tillage into 4.39 t/ha Brachiaria mulch with some Wynn Cassia and Senna. Development: 1st square 3-Feb-21, 1st flower 24-Feb-21, Cut-Out 30-Mar-21, 60% Open Bolls 15-May-21, Pick 19-Jun-21. Max LAI – 2.9 on 30-Mar-21. Yield 5.64 b/ha. Soil water to 210 to 240 cm measured on 3/2/21, 9/4/21, 7/5/21, 22/6/21 (350 cm), methods as per Row Spacing 2021. In crop rainfall 936mm. The soil in the field was characterised for APSIM using the soil water measured above and other soil parameters measured in situ by NT DEPWS (Edmeades, 2021). The soil was classified as a Tindal.

RESULTS APSIM-OZCOT calibration and validation

Calibration-plant parameters

Five model parameters were recalibrated to account for changed cotton, root growth rate, leaf area, fruiting dynamics and development time in the tropics (Table 1).

Changes reflect the differences in morphology and crop development measured in tropical environments with well drained soils. That is: deep roots, rapidly expanding large thin leaves, first fruiting branch location and the time to square appearance. Many of these changes were reported previously (Grundy et al. 2020, Yeates et al. 2010, Grundy et al. 2012).

Table 1: *Plant parameters requiring changes*

Parameter	Unit	Description
rtdep_max	cm	Maximum depth of rooting
rootLACrit	m^2 $plant^{-1}$	Critical leaf area per plant limiting root expansion
Sqcon	sites degree day^{-1}	Squaring constant
DDISQ	degree days	Thermal time between seedling emergence and first square appearance
dlds_max	$\sqrt{(m^2\ m^{-2}\ site^{-1})}$	Square root of leaf area increase per site

Table 2 shows the magnitude of changes to plant parameters were large.

Table 2: *key OZCOT model plant parameter departures*

Parameter	Default	Tropics	Difference %
rtdep_max	150	300	100
rootLACrit	0.012	0.001	-1200
sqcon	0.0217	0.014	-35
DDISQ	486	540	11
dlds_max	0.12	0.17	42

Lint turnout also required local calibration; the average of observed values from machine picking and commercial ginning of the trial and validation fields were used in the simulations, these ranged from 39 to 41% depending on variety.

Calibration – soil parameters

In-situ measurement of key soil parameters permitted volumetric soil water to be simulated with close agreement with observed soil water profiles early and late in the season and below 60 cm for the whole growing season (Fig. 1).

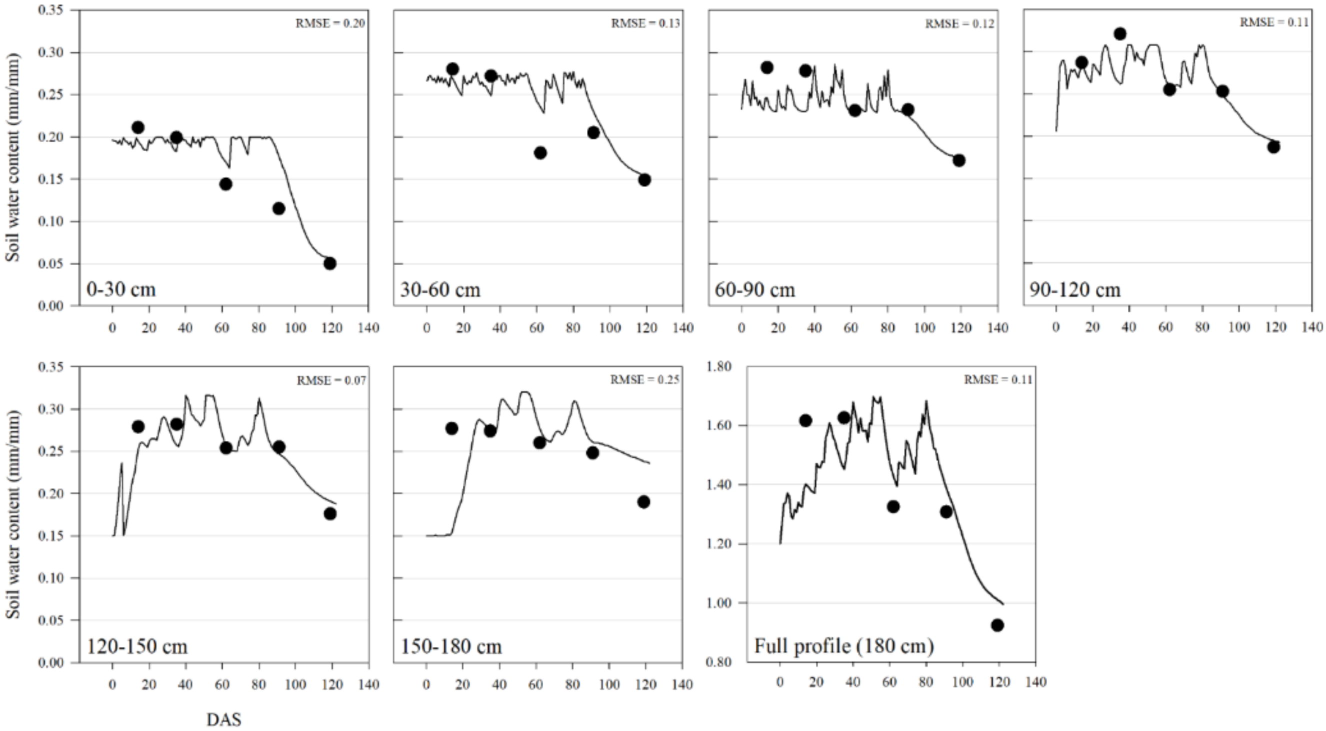

Fig. 1: *Comparison of simulated and observed values of the seasonal changes in soil water content (mm/mm) after calibration and measurement of soil water parameters in-situ. Shown are depths are where a complete set of samples could be taken. Date source: row spacing experiment 2021, Tindal soil.*

Validation

Plant parameters

Figure 2 shows the model validation results for 4 rain gown and 2 overhead irrigated cotton crops grown over 3 seasons 2019 to 2021. Lint yield and LAI were accurately simulated for the rain grown crops and time to maturity was poorly predicted for all crops. However, it should be noted that one dryland crop matured prematurely due to pre-mature senescence of leaves (Field A, Crop Monitoring Reports 2020).

Simulating irrigated crops sown mid wet season then finished with irrigation in the early dry season has proven problematic at research sites in north Queensland and in the Kimberley. The subsequent compensatory growth of leaves and fruiting sites that follows fruit shedding when irrigated crops are exposed to cloudy weather during the monsoon season (Grundy et al. 2020), rarely occurs outside the tropics, hence required new research to enhance the OZCOT model.

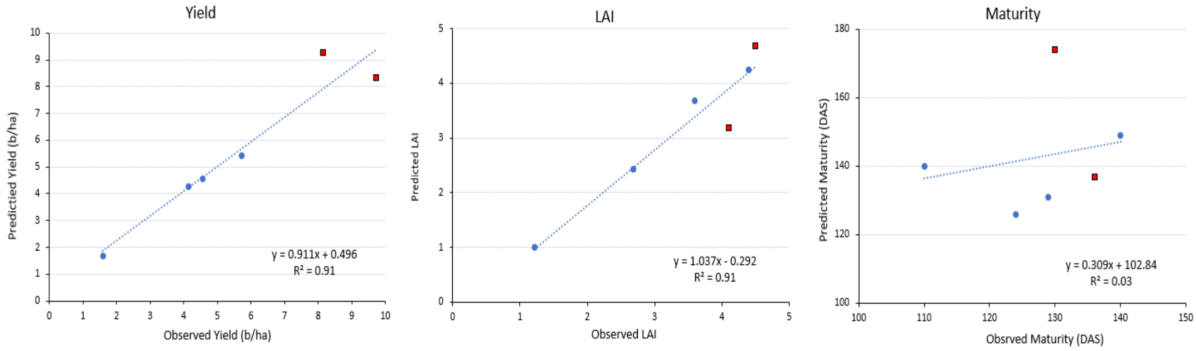

Fig. 2: *APSIM-OZCOT validation for plant parameters lint yield (bales/ha), leaf area index (LAI) and days after sowing (DAS) to maturity (60% open boll) for six sites in the Northern Territory, 2019-2021. The red points circled are irrigated cotton.*

Soil water extraction

Fig. 3 shows very good model simulation of soil volumetric water content over the cropping season to 210 cm

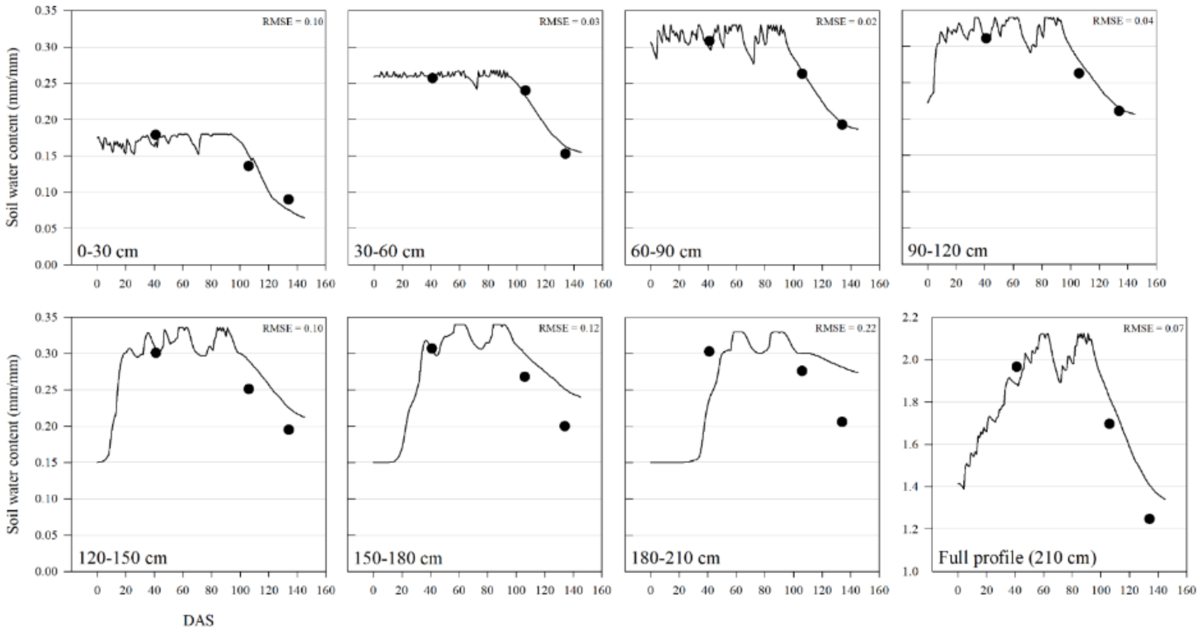

Fig. 3: *Validation of simulated vs observed seasonal changes in soil water content (mm/mm) using previously calibrated (Fig SWC) and site specific measurement of soil water parameters. Shown are depths where a complete set of samples could be taken. Data source: Billabong field Tindal soil 2021.*

B. Modell Application Studies

1. Impact of planting date and available soil water on yield in one season

Methods

In the Douglas Daly region the Tindal soil characterised at the row spacing experiment field was measured to have 27mm less available water to cotton than the nearby Tindal soil characterised at the Billabong field (3 km SE). In addition the Billabong field was sown 14 days earlier than the row spacing field. This created an opportunity to apply the OZCOT-APSIM model to evaluate two "what if" Scenarios:

Scenario 1: Impact of 27 mm greater available soil water when planting late in the window (7 – January) at the row Spacing field. That is using the model to grow the row spacing crop but substitute the 'billabong" field soil, leaving all other management the same.

Scenario 2: Effect of sowing 2 weeks earlier at the row spacing field, i.e. same date as the Billabong field, 24 December instead of 7 January. That is using the model to grow the cotton at the earlier in sowing date field (soil) using the same, climate and management with timings corrected for sowing date.

The above scenarios simulated cotton yield grown in 1m row spacings, as the OZCOT model yet to be calibrated for 1.5 or 0.5 m row spacings in the tropics.

Results

- Scenario 1: Increasing the available soil water (+27mm) without any changes to management or climate increased lint yield by 9% (Table 3)
- Scenario 2: Planting 14 days earlier on a soil with lower available soil water (-27mm) without any other changes to management or climate increased lint yield by 18% (Table 3).

Table 3: Simulated cotton yield for available soil water and planting date scenarios.

Scenario 1		**Scenario 2**	
Plant Available Soil Water	**Yield (b/ha)**	**Planting date**	**Yield (b/ha)**
141 mm	4.5	24 Dec	5.3
168 mm	4.9	7 Jan	4.5

- This analysis, using accurately characterised soils, demonstrated the importance of available soil water and timely planting rain grown cotton yield.

2. Comparison of possible NT cotton growing locations, soils and management on long term cotton yield (1957 to 2022).

Methods

Simulation Set Up

Using APSIM Classic version 7.10, three sowing windows were compared:

(1) Default planting 15 Dec to 15 Jan, (currently preferred planting time)

(2) Early planting 1–15 Dec

(3) Late planting 15 Jan to 1 Feb

Within each sowing window at five locations each with three soils were compared (Table 4, Figs. 4 & 5)

Table 4. APSIM-OZCOT simulation combinations for region and soil type. Annual rainfall is also shown.

Region	Location		Annual rainfall (mm)	Soil type		
				Blain	Oolloo	Tippera
Daly Basin	Tipperary	13.74°S, 131.04°E	1325	✓	✓	✓
	Douglas Daly	13.83°S, 131.19°E	1245	✓	✓	✓
	Katherine	14.47°S, 132.31°E	1088	✓	✓	✓
Roper Valley	Ngukurr	14.74°S, 134.53°E	744	✓		✓
Sturt Plateau	Larrimah	15.57°S, 133.21°E	860	✓		✓

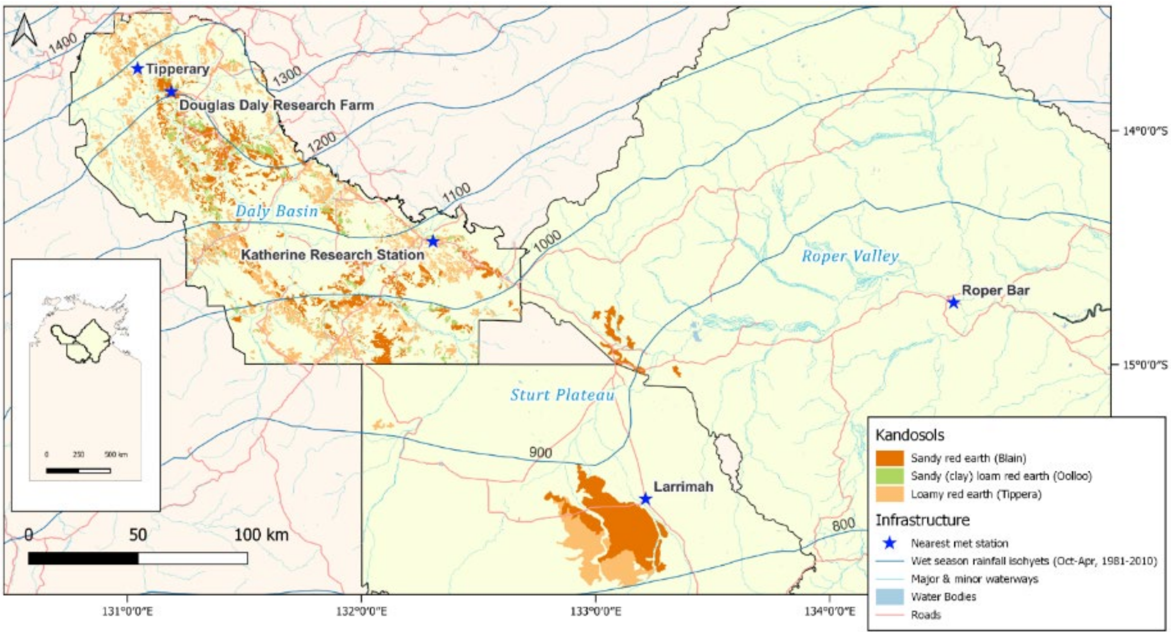

Fig. 4: The locations (weather data) where simulations was conducted including the area and known distribution of the key arable soils used in this analysis. NB Roper Bar is 15 km east of Ngukurr; the agriculture land and water suitability the Roper Catchment is currently under assessment by CSIRO hence its inclusion in this report (Map from).

Soil details

Soils representing the most common cultivated Kandosols within the regions were used in the simulations (Fig 4). The Blain (PAWC~ 140 mm) and Tippera (PAWC~80 mm) soils had been previously characterised for APSIM by CSIRO (P. Poulton pers com.). While a representative Oolloo soil (PAWC ~130 mm) was characterised from data collected in the "Farm Monitoring studies 2020" report and Edmeades (2020, 2021). Volumetric soil water profiles are shown in Fig. 5.

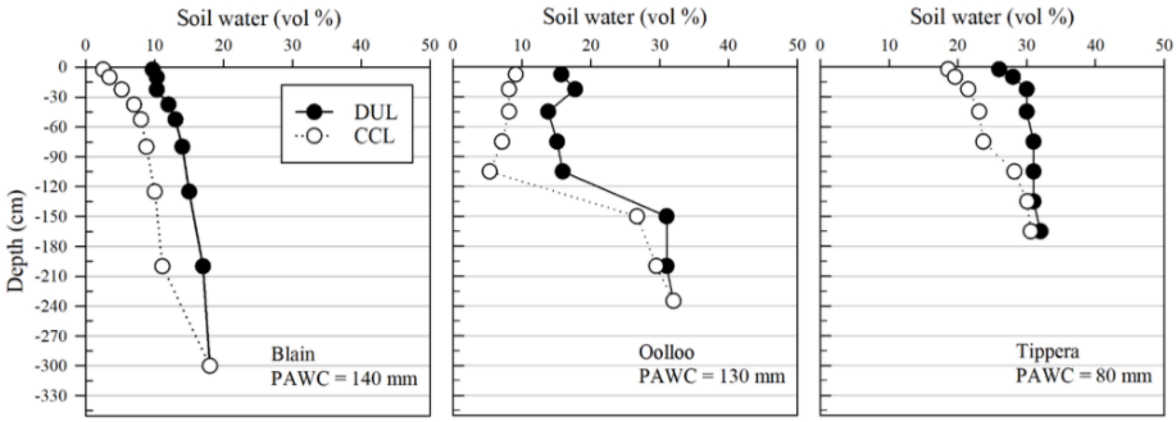

Fig. 5. *Measured volumetric water content for representatives of the most common NT Kandosols (Blain, Oolloo, Tippera) used in this APSIM-OZCOT application study.*

To account for the expected heterogeneity of NT Kandosols for plant available soil water the sensitivity of cotton yield was tested for some variants (unpublished) of known cultivated soils by increasing/decreasing the drained upper limits. These were Blain (80, 160 mm), Oolloo (80, 152 mm) and Tippera (120 mm).

Cotton management settings

Sowing commenced after a total of 30 mm of rain within 3 days and at least 20 mm of soil water, at 30 mm depth, 7 plants m^{-1} row, and 1 m row width as per industry practice. Sowing was zero-tillage into soil mulch cover which consisted of initial surface residue of 1,000 kg ha^{-1} and carbon to nitrogen (C:N) ratio of 35, on 30 September, a sorghum cover crop was then planted (sowing window 15 Oct to 31 Dec) and grown pre sowing rain. The cover crop was killed once 2 t ha^{-1} dry weight is achieved to form a surface mulch at the time of cotton sowing.

Nitrogen fertilizer 100 kg N ha^{-1} was split 50:50 between planting and first flower (30 days after sowing), which is realistic for a rain-grown yield of 5 bales ha^{-1} (CRDC and Cottoninfo, 2018). Because optimal N fertiliser rate is soil and region-specific (Biggs et al., 2021), yield sensitivity to a 50% higher N rate was tested.

Results

1. **Median lint yield simulated at five NT locations and three soils, within the default planting window (15 December to 15 January)**

Figure 6 shows:

- For all regions, the range of median lint yields was 5.5 to 2.9 b/ha with Tipperary & Douglas Daly > Katherine, > Ngukurr & Larrimah, and Blain ≥ Oolloo > Tippera. Which reflected seasonal rainfall volume and plant available soil water at each region.
- Importantly for all locations and soil types, the range in yields from the median were very large (95 to 130% of median). Indicative of high between season variability in growing conditions (most likely rainfall).
- Median lint yield in the highest 10 % of seasons was ≥ 7 b/ha for the greater PAWC Blain and Oolloo soils, at Tipperary and Douglas Daly, at other locations median yield was ≥ 5 b/ha. For Tippera soils median lint yields in the highest 10% seasons was ≥ 3.9 to 5.7 b/ha

- Due to lower PAWC median cotton yield on Tippera soils was 0.6 to 1 b/ha lower than the Brain and Oolloo soils at all locations except Larrimah
- For the lowest 10% of seasons, lint yields at Tipperary, Douglas Daly and Katherine were ≤ 1.8 to 2.9 b/ha on Blain and Oolloo soils, Tippera soils ≤ 1.0 to 2.2 b/ha all sites. The narrower yield range due to insufficient rainfall at all locations.

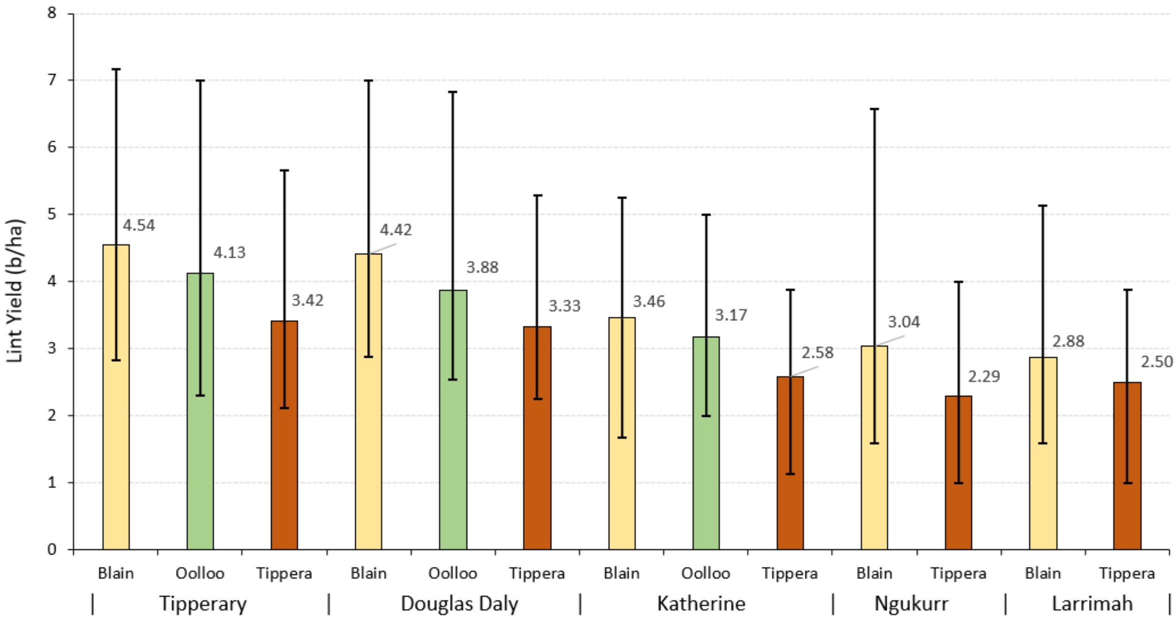

***Fig. 6:** Simulated lint yield for commonly cultivated NT Kandosols (Blain, Oolloo, Tippera) at five locations, default planting widow 15-December – 15 January. Columns are the median (50% of seasons) and error bars 10 to 90% of seasons (1957–2021). NB Oolloo soil is rare at Ngukurr and Larrimah (Fig. 4), hence not included.*

2. **Sensitivity of median lint yield to planting window and soil PAWC. The number of planting days within the default window (15 December to 15 January)**

Table 5 shows:

- There were significant yield penalties (17 to 40%) for late planting (≥ 15 Jan) at all sites and soils.
- The yield benefit of growing cotton on soils with greatest available water was strongly demonstrated at all locations and soils, particularly the Tippera soils. The median yield loss for the soils with lower PAWC of 14 to 26% at Tipperary, Douglas Daly and Katherine is undesirable.
- There are potentially significant yield gains (9 to 24%) from earlier planting at the higher rainfall locations, Tipperary and Douglas Daly. Early planting was only possible in 14 to 20 % of seasons at these locations.
- Large yield increases were simulated for early planting at Larrimah because the crop was able to capture more in crop rainfall prior to the termination of the wet season, however planting was only possible in a small percentage of seasons.
- The ≥ 110% yield gains simulated for Ngukurr when sown early were from the only 2 seasons where planting was possible. The yields at Ngukurr are analysed in more detail below (Fig. 7).

Table 5: *Sensitivity of median lint yield to planting window and soil PAWC, shown as percentage change from default planting window and PAWC. In brackets are the number of seasons planted of the 64 simulated. Default = sowing 15 December to 15 January.*

Location	Soil type	Default Yield b/ha	Sowing Date		PAWC	
			Early 1-14 Dec % Default Yld	Late ≥ 15 Jan % Default Yld	Low % Default Yld	High % Default Yld
Tipperary	Blain	4.5 (56)	+11 (20)	-36 (57)	-18	+7
	Oolloo	4.2 (57)	+12 (15)	-41 (57)	-26	+2
	Tippera	3.4 (58)	+13 (14)	-40 (58)	NT	+18
Douglas Daly	Blain	4.4 (61)	+15 (20)	-36 (59)	-14	+3
	Oolloo	3.9 (60)	+9 (17)	-40 (59)	-20	+6
	Tippera	3.4 (60)	+24 (17)	-42 (59)	NT	+15
Katherine	Blain	3.4 (50)	+5 (10)	-33 (51)	-24	+4
	Oolloo	3.1 (52)	+2 (8)	-23 (50)	-25	+9
	Tippera	2.6 (50)	-4 (8)	-23 (51)	NT	+19
Ngukurr	Blain	3.5 (20)	+120 (2)	-26 (32)	-8	+5
	Tippera	2.3 (23)	+110 (2)	-17 (32)	NT	+15
Larrimah	Blain	2.9 (37)	72 (8)	-32 (46)	-8	+5
	Tippera	2.5 (37)	35 (5)	-37 (46)	NT	+15

NB. Douglas Daly = Research Farm, Katherine = Research Station

Median lint yield was not sensitive to an increase in N fertiliser rate from 100 kg N /ha to 150 kg/ha for all regions and soils, (data not presented).

3. Frequency of sowing on at least 1 day and the number planting days within the default window (15 December to 15 January).

Table 6 shows:

- For the well-drained soils compared in this analysis, lack of rainfall or insufficient soil cover at planting were the major causes for not planting. Both causes are linked to water availability prior to and at planting. Note: this sowing rule used in this analysis prioritised sufficient much cover as the first trigger to commence planting.
- As expected, the number of seasons planted was highest at locations with the greatest volume of rainfall prior to the planting window start (< 15 December).
- To increase the frequency of timely planting in drier regions a rotation where surface stubble from an alternative crop to cotton (e.g. sorghum or forages) is carried over from the previous season to complement live cover grown from rainfall prior to sowing, should be considered.
- Too wet to sow was not simulated, based on experience this is unlikely to be significant on these well drained soils prior to mid-January.
- The median number of planting days within the 32 day "default' window ranged from 8 to 5 as the seasonal rainfall declined Tipperary > Douglas Daly > Katherine > Larrimah and Ngukurr.

Table 6: *The median number of seasons in the default window (15 December to 15 January), when sowing was not possible on at least 1 day, the median number of planting days within the default window and contribution of insufficient mulch cover or dry soil to not planting.*

Location	Soil type	Number of seasons not sown (/64)	Number of Planting days	The reason (number of seasons)	
				Insufficient mulch cover	Soil too dry
Tipperary	Blain	8	8.5	5	3
	Oolloo	7	8	4	3
	Tippera	6	8	4	2
DDRF	Blain	3	7	1	2
	Oolloo	4	6	3	1
	Tippera	4	7	2	2
KRS	Blain	14	6	9	5
	Oolloo	12	6	8	4
	Tippera	14	5.5	9	5
Ngukurr	Blain	44	6	32	12
	Tippera	41	5	31	10
Larrimah	Blain	27	6	15	12
	Tippera	29	4	19	10

Simulations for Ngukurr (Roper Bar) in the Roper catchment showed the greatest increase in yield (110 - 120%) with earlier planting (Table 5). This is explained by a higher average and proportion of seasonal rainfall later in the wet season which extended the growing season length compared to Kathrine and Larrimah (Fig 7). However planting opportunities at Ngukurr were greatly reduced compared to Kathrine and Larrimah due to the lower pre December rainfall delaying the establishment and growth of mulch cover (Table 6); exacerbated at the early December planting window when sowing was only possible in 6 to 7% of seasons (Table 5).

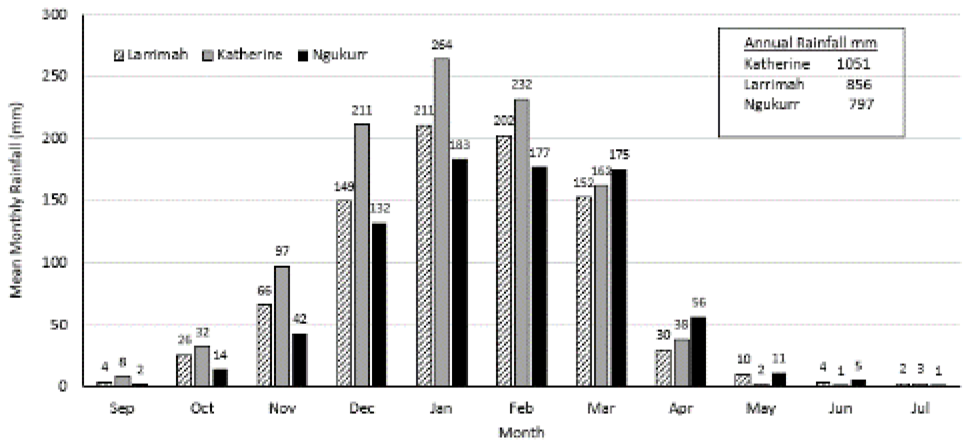

Fig. 7: *Comparison of monthly long term average rainfall for Ngukurr compared with Katherine and Larrimah to the East and NNE east (Map).*

C. Implications of model application for NT cotton land suitability assessments.

Background

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. Several recent reviews have identified the location of sufficient hectares suitable land for cotton industry development (NT farmers 2019) with suitable hectare calculations based on a combination of local farmer opinion and published land suitability assessments.

Pasco-Bell et al. (2014) is only large scale NT study to identify suitable areas for rain grown crops by overlaying seasonal rainfall with soil characteristics (Fig NT). Suitable growing areas were defined as having well drained soils with soil depth ≥ 90 cm and slope ≤ 2%, receiving a monthly rainfall ranges of Dec 130-210 mm, Jan 165-292, Feb 177-305 mm Mar 125-235 mm.

The Pasco-Bell assessment has several limitations for cotton suitability.

- Tipperary and other areas with similar rainfall (e.g. upper Adelaide River) are excluded due to exceedance of the upper rainfall threshold, despite the presence of suitable well drained soils and successful rain grown cotton production in higher rainfalls in Brazil.
- The minimum soil depth criteria of 90 cm is likely to be too shallow for well drained Kandosols, moreover as the application study (Section 2) shows 90 cm will not reliably provide sufficient soil water for rain grown cotton particularly in lower rainfall areas.
- The minimum seasonal rainfall threshold may exclude regions with slightly less rainfall combined with deep soils of high available water, e.g. Larrimah and much of Sturt plateau should deep soils exist there.
- For areas such as Ngukurr (eastern Roper Catchment), due to a later end of the wet season, April rainfall should be included in the optimal rainfall criteria.

Implications from the OZCOT-APSIM simulation studies

- In the short to medium term, locating soils on existing cleared land with high availability of water to cotton is critical to reliable and acceptable yield of rain grown cotton in the NT. This criteria is best met by identifying Kandosol soils that permit deep penetration of cotton roots ≥2 m, (preferably 3m). Kandosols are trafficable in the wet season and dominate Tipperary-Daly Basin-Sturt Plateau region (Fig. 4). The amount of physical sampling required to identify fields with higher available soil water can be reduced if landscape and landholder experience is incorporated into surveys (e.g. previous or remaining native vegetation indicators and where pastures stay green longer into the dry season and remain trafficable in the wet season).
- Timely planting is critical and will significantly increase median yield, however large seasonal variation in yield will remain. Practices / technologies that can increase the chances of timely planting and maximise planting days will need to evolve during the early years of cotton industry development.
- A consideration for early December planting in higher rainfall regions (Tipperary, Douglas Daly) is an increased risk of pre picking rainfall discolouring cotton fibre, as the majority of bolls are likely to open in late March – early April (Yeates and Poulton 2019). Rainfall volumes of > 150 mm and > 100 mm are possible in late March and April respectively in 10 % of seasons at Tipperary and Douglas Daly.
- For lower rainfall regions (Katherine and south) timely crop establishment is critical as rain prior to planting can be insufficient to grow soil cover to protect seedlings from high soil temperatures, rapid drying of the planting slot and surface crusting. Cropping systems that carry over soil cover from the previous wet season (e.g. sorghum or forage grasses) are an option to mitigate this risk.
- As NT cotton production in the short to medium term will use existing cleared land, cotton will need to demonstrate a competitive advantage over the current land use. An economic assessment

that calculates long-term annual gross margins from simulated cotton yields produced from the farming system, is needed to determine the regional prospects for cotton, particularly for the lower yielding drier regions.

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Cotton Row Spacing Comparisons – 2021 and 2022

Report prepared by: Stephen Yeates & Tiemen Rhebergen, CSIRO
Project Team: NT- DITT: Nick Hartley, Cameron Crawford, Peter Shotton
CSIRO: Jenny Stanford, Rowena Eastick, NT- DEPWS: Jason Hill

SUMMARY

Background / Aim: These trials were in response to grower feedback to the NT Farmers asking whether row spacings other than the traditional 1m would provide higher and more stable rain grown cotton yields in the NT.

Methods: Two replicated trials with three row spacings 0.5, 1.0 and 1.5 m (same plant density per m of row), were implemented 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 growing season is greatest. Measurements focused on yield, time to maturity, soil moisture extraction and crop inputs. Due to resource constraints less data was collected in 2022.

Key Findings:

- In 2021 no significant lint yield difference between row spacings was measured, the treatments averaging 3.9 b/ha.
- In 2022 lint yields 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.
- The 0.5m row spacing reached maturity 14 & 10 days earlier than the 1.0 m and 1.5 m spacings in 2021 and 2022 respectively. The 1.5m spacing matured only 1 to 2 days later than 1m.
- The earlier maturity of the 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 spacings where > 50% of yield was on later flowering bolls.
- Row spacing did not affect fibre properties, which were at least "Basis' (no discount).
- There was no significant difference in the volume of soil water extraction between row spacings.
- The volume and timing of in-crop rainfall influenced the yield responses to row spacing. In 2021 until late flowering the crop used above median in-crop rainfall, then accessed available soil water until maturity; sufficient for the 0.5m and not sufficient for the longer flowering wider rows to take advantage, hence similar yields. In 2022 the crop relied on soil water from 1st flower (mid-March) until at least week after cut-out (mid-April) for all treatments and was exposed to above average temperatures; a scenario favourable to narrower row spacings; above median rainfall in mid-April assisted all row spacings.
- 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.

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 spacings 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 spacings 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.

COMMON METHODS

Over two seasons 2021 and 2022, three row spacings 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 spacings 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

<u>2021 Trial</u>

METHODS 2021

Field, crop details and management inputs are provided in Tables 1-3.

Table 2: *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 3: *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: *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

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.

RESULTS 2021

Climate:

- Table 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 5: *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 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.

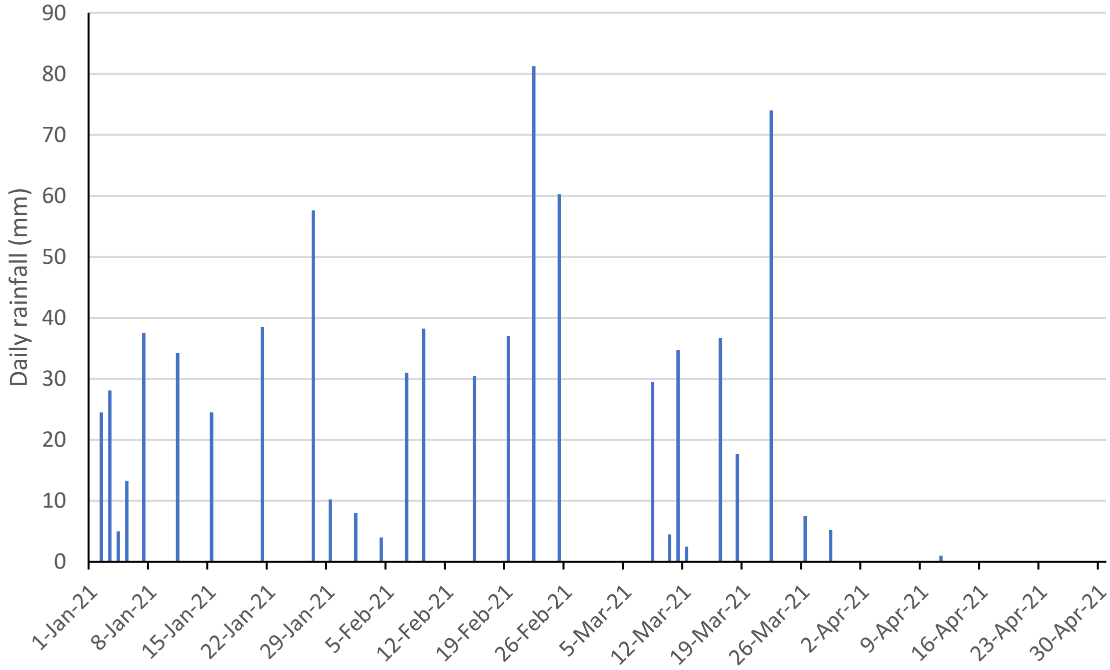

***Fig. 1:** Daily rainfall volumes measured with the meteorological station at the trial site.*

- 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 6: Growing season monthly average daily solar radiation and temperature compared to long term average (LTA) or median (LTMd).

Month	Solar Radiation (MJ/m^2)		Tmax (C°)		Tmin (C°)	
	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 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 7:** Mulch cover properties.*

Cover	**Date sampled**	**Dry weight kg/ha (se)**	**Carbon %**	**N %**	**N kg/ha**	**C:N**
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

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

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

Soil chemical properties and soil water:

- Table 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 8: *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 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 9: 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 2 shows the change in gravimetric soil water (%) by depth throughout the growing season for 0.5, 1.0 and 1.5 m row spacings:

- There was no significant difference in soil water extraction between row spacings 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.

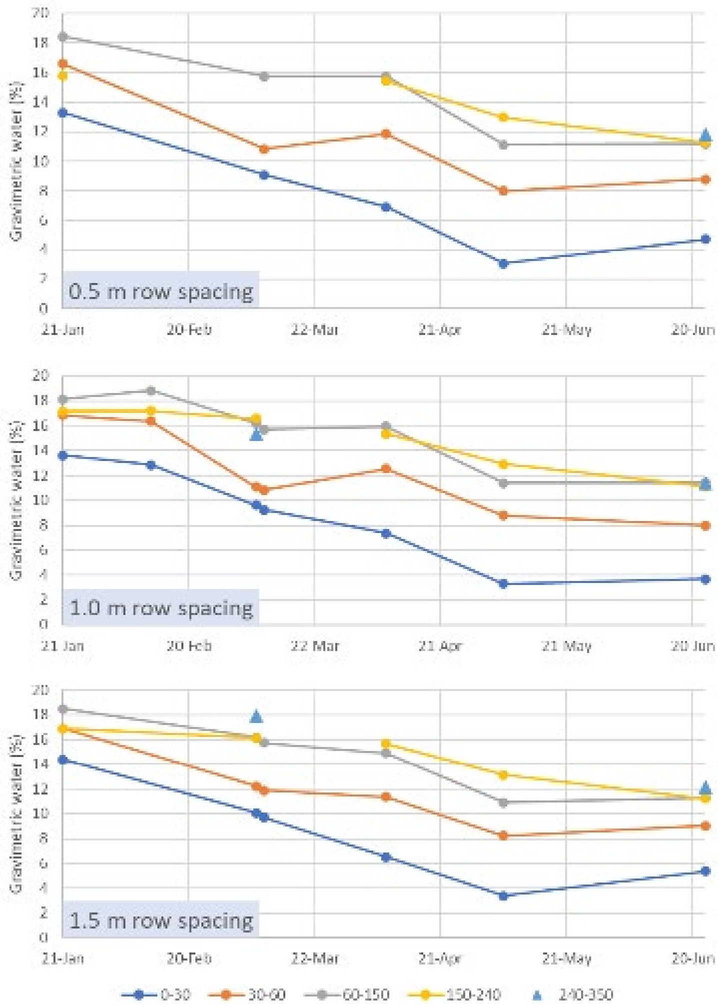

***Figure 2:** Seasonal change in gravimetric soil water (%) with soil depth (cm) for 0.5, 1.0 and 1.5 m row spacings.*

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 spacings, 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 spacings (Table 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), (Fig. 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 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 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 3).

Table 10: *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

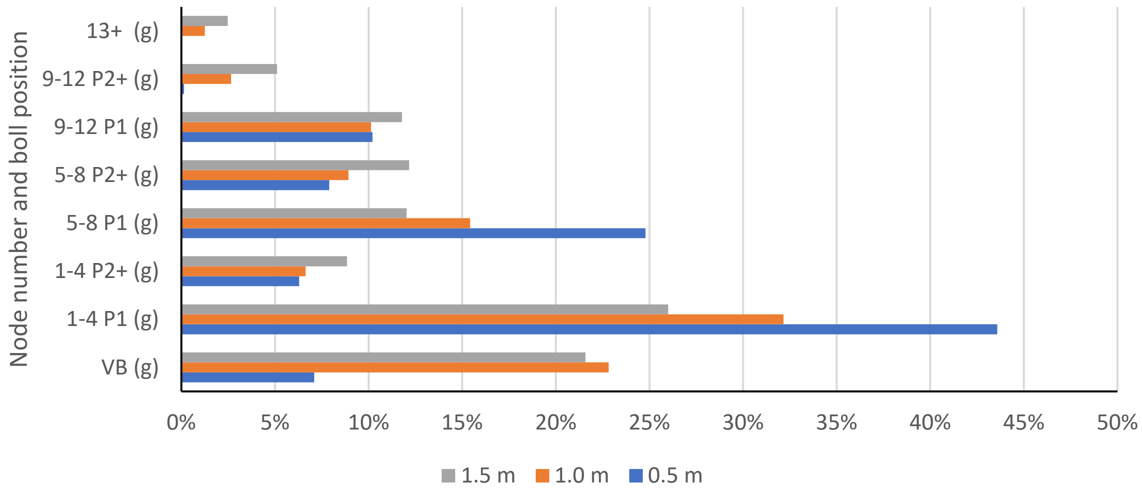

Fig. 3*. Within plant Yield distribution (% of total) of the 0.5, 1.0 and 1.5 m row spacings.*

2022 Trial

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.

  

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

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.
- 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 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

January 2022, Left: Sowing, Centre and Right: crop establishment and past cotton stalks

RESULTS

Climate:

Table 11 and Fig. 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 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°)		Tmin (C°)		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

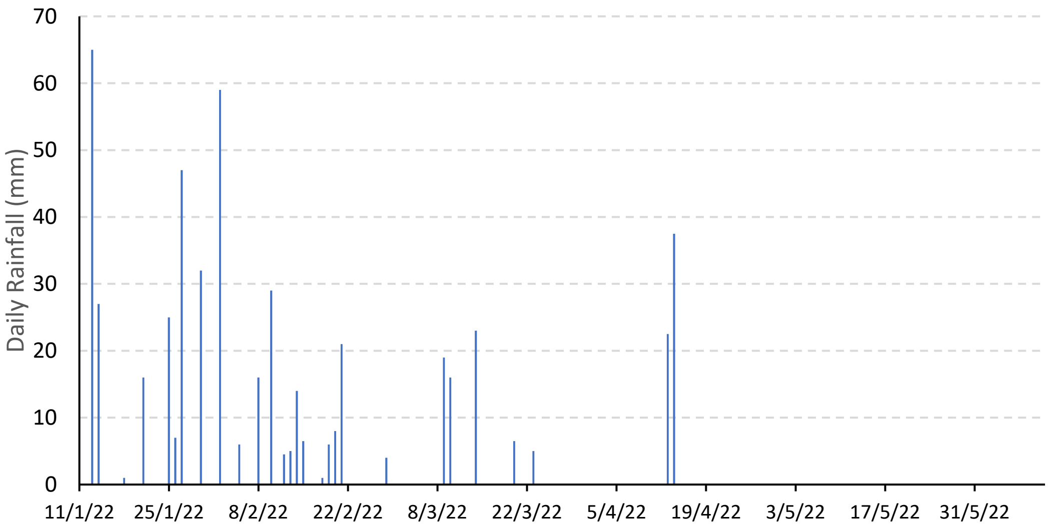

Figure 4: *Growing season daily rainfall. NB planting was on January 25, 2022*

March 7, 2022: canopy development at early squaring

April 12, 2022: water stress symptoms post cut-out in all row spacings

Crop development:

- Table 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.

Table 12: *Development dates and final boll number. The only significant differences where the 0.5m row spacing was earlier for time to cut-out and maturity.*

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

June 8, 2022: Picking

Yield:

- Figure 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.

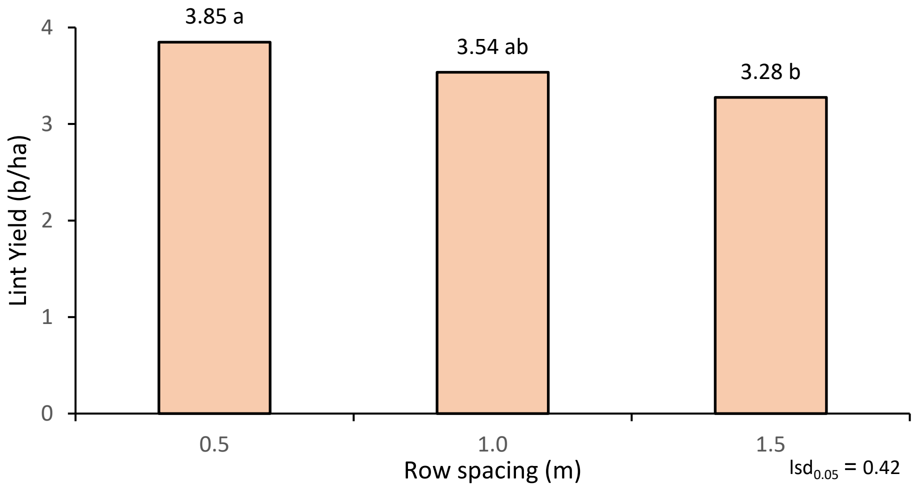

Fig. 5: *Yield 2022, means with the same letter are not significantly different.*

ACKNOWLEDGEMENTS

The project team appreciate the assistance provided by Bert Parker, Jamie Marschall and staff of the Douglas Daly Research Farm, Sam McBean of 'Ruby Downs' for planting the experiment in 2021, and Jess Langridge CSIRO.

Final Results Report for CRCNA project A.2.1819004 potential for broadacre cropping in the NT.

Monitoring of Commercial Cotton Fields 2019 / 20 wet season

Prepared by: Stephen Yeates, CSIRO
NT- DITT; Ian Biggs, Nick Hartley, Millie Lamprecht, Peter Shotton
Project Team CSIRO; Jenny Stanford, NT- DEPWS; Jason Hill

SUMMARY / KEY FINDINGS for ALL CROPS MONITORED

Background: Monitoring of commercial crops was initiated to complement this CRCNA project's objective to assess the natural resource to provide for agriculture and the cropping potential of cotton. This work commenced in late 2019 coinciding with the expansion of commercial scale test farming of wet season grown cotton, a new opportunity for the NT. Consequently all farmers were new to growing cotton in the region.

Aims: In commercial cotton fields, measure seasonal soil water and nitrogen availability to cotton, crop growth and yield, then apply this data support crop management, R&D priorities and assessment of climatic risk and intraregional opportunities.

Methods: 3 rain-grown and 3 irrigated cotton fields were monitored in the Douglas Daly – Tipperary region. Measurements were taken pre planting then at regular intervals until crop destruction and included soil cover, soil water and N, crop growth and development, pests and weeds, yield and fibre quality.

Key Findings:

- In-crop rainfall (January to April) was near the long-term median with exception of 2 fields with below median March rainfall.
- Prior to fertiliser application soil organic carbon was very low and available nitrate the same indicating crop N supply from these sources would be very limited.
- In-crop soil water extraction post wet season by rain-grown crops was measured to between 180 and 210 cm, the maximum depth of the sampling equipment.
- Post picking sampling using the NTDEPWS pneumatic soil corer found roots and dry soil to between 230 and 300 cm in Oolloo soils and 180 to 240 cm in Tippera soils where there were no limitations to roots (e.g. rocks). Future monitoring will require deep coring at the start and end of the growing season.
- After picking there was no evidence of soil nitrate accumulation below 150 to 210 cm in any field. Soil nitrate remained very low above these depths. Applying a significant proportion of N fertiliser in-crop by mid flowering was a successful strategy.
- Rain grown lint yields ranged between 3.6 and 4.1 b / ha, irrigated 7.0 to 9.1 b/ha, a good result as a first attempt. Fibre quality was at least at market preference (basis) for the great majority of lint produced.
- Site specific details are in the report below.

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 to:

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.

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. 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.

GENERAL METHODS & 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 recorded 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.

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

CROP MONITORING REPORTS

1. FIELD A – RAIN GROWN

METHODS

Table A1: Field and Crop details

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

Table A2: Applied Fertiliser

			Nutrient Kg/ha								
Date	**Product**	**Product 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 A3: 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 “Trace Brew” 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.

29 February 20 - Jarrah mulch

RESULTS

Climate

- Table A4 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 A4: 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 A1 shows within season rainfall variability was high particularly for the “critical” period from late February to mid-April.

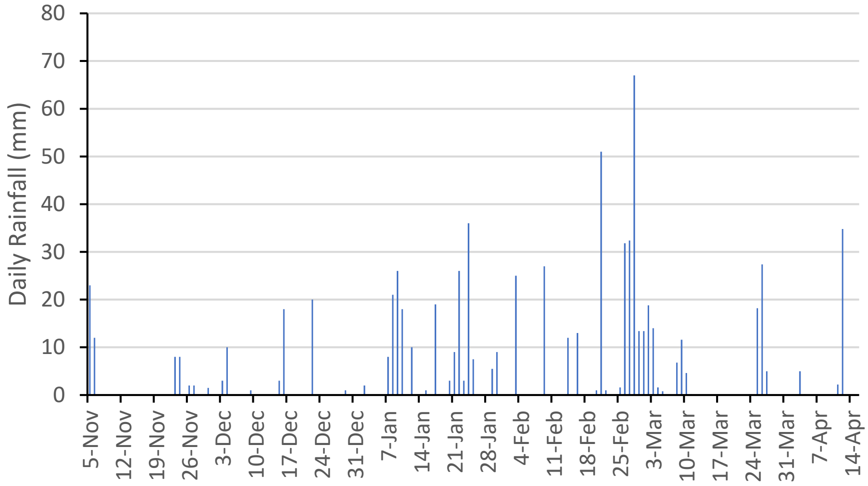

Figure A1: Daily rainfall volumes. Total post planting = 617 mm

Table A5: Average daily solar radiation and temperature

	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

Mulch Cover Properties.

- Table A6 shows soil cover from pervious Jarrah 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 2), hence decomposition was sow and would have tied up some soil N.

Table A6: Mulch Cover details

Cover	Date Sampled	Ground Cover %	Dry weight kg/ha (se)	Carbon %	N %	N kg/ha	C/N
Jerra Grass	24-dec-19	98	7327	42.0	1.36	100	45.3

Soil Properties: Water, Nitrate and Organic Carbon.

- Table A7 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 A7: 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 A8 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 A8: 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 A2 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.

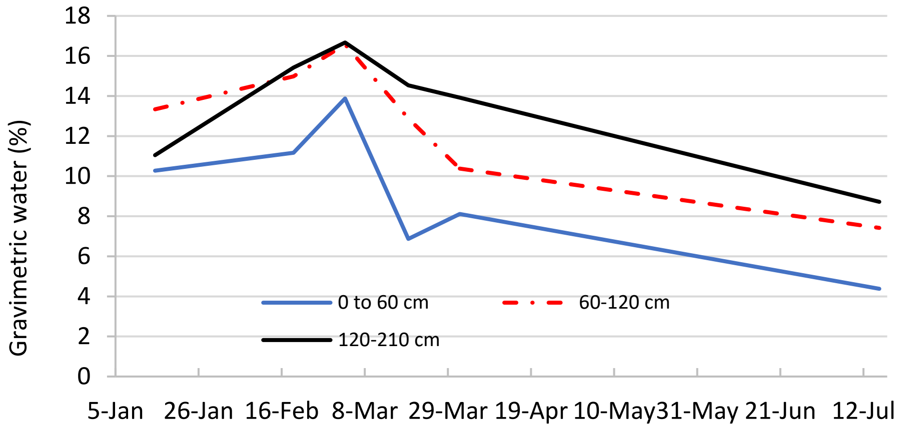

Fig. A2: Seasonal change in gravimetric soil water (%) with soil depth

1 April 2020 – premature senescence like symptoms on leaves

Crop Details

Table A9 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, earlyish 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 A9: 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
Fibre 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 Jarrah 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, earlyish 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.

2. FIELD B – RAIN GROWN

METHODS

Table B1: 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 B2: Applied Fertiliser

			Nutrient Kg/ha								
Date	**Product**	**Product** 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 B3: 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 "Trace Brew" 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.

16-January-20: Soil sampling at planting, note patchy ground cover.

16-January-20: Soil surface crust and seedlings prior to emergence

28 July 2020 post picking coring to > 3m

RESULTS

Climate

Figure B1 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.

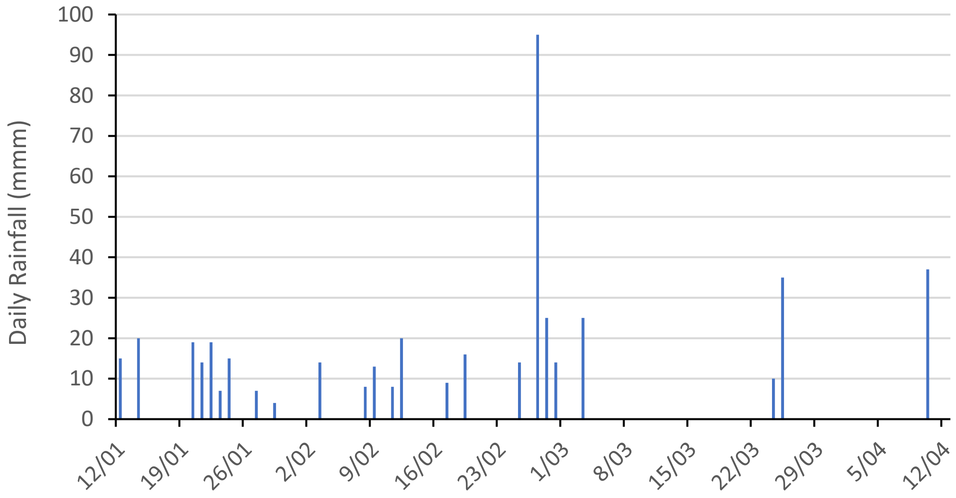

Fig. B1: Daily Rainfall volumes (Total 463 mm)

Table B5: Average daily solar radiation and temperature

	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

Mulch Cover Properties.

- Table B6 shows grain sorghum stubble from the previous wet season was variable and well decomposed prior to planting.

Table B6: Mulch Cover details

Cover	Date Sampled	Ground Cover %	Dry weight 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 B7 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 B7: 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 2 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.

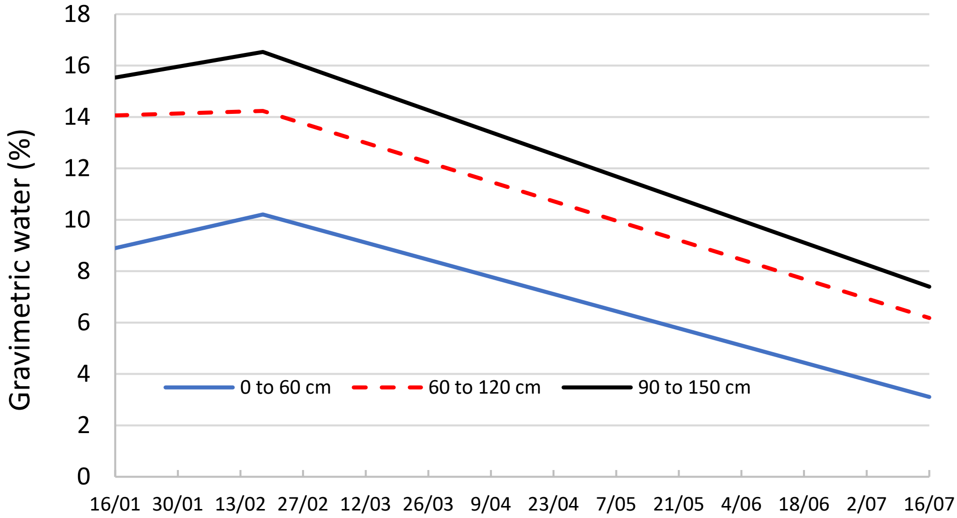

Fig. B2: Change in gravimetric soil water (%) with soil depth

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 B8: 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 Picking 24-June
Yield (bales / ha)	Hand-picked in uniform areas 4.5 (± 0.8) Field machine picked 3.6
Lint %	36.19
Fibre 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. FIELD C – RAIN GROWN

METHODS

Table C1: 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 C2 and C3.

Table C2: Applied Fertiliser

			Nutrient Kg/ha								
Date	**Product**	**Product 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 C3: 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 C4: 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 C5: Average daily solar radiation (MJ/m^2) 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 C2 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

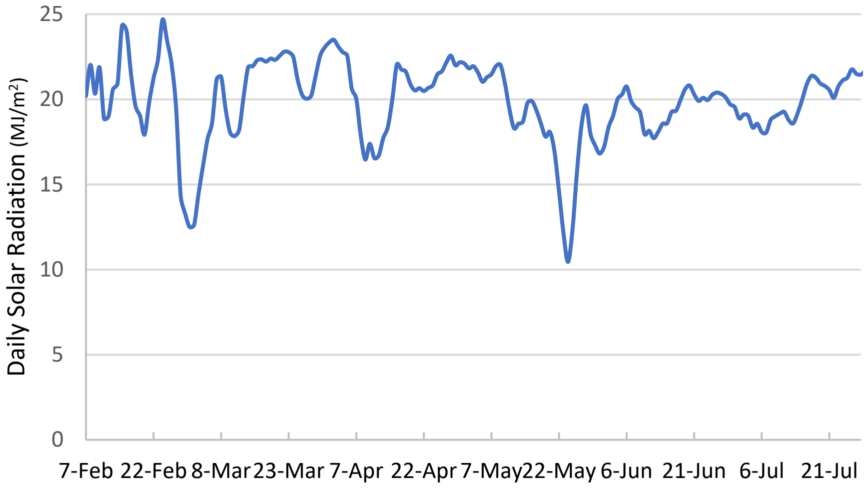

Fig. C2: Daily solar radiation for the growing season (shown as a 4 day moving average)

5 March 20 – large leafy plants at early flowering

Soil Properties: Water, Nitrate and Organic Carbon.

Table C6 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 C6: 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 C7 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 C7: Seasonal change in soil nitrate by depth. 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.

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

7 April 20 – large plant shedding fruit

Seasonal change in soil water and depth of water extraction.

- Figure C3 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.

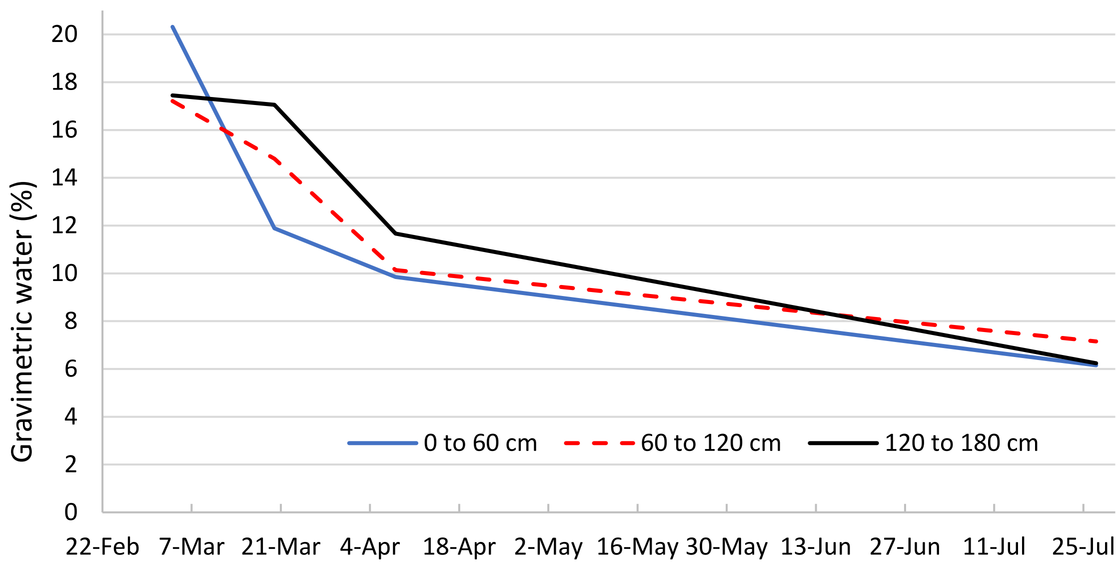

Fig C3: Change in gravimetric soil water (%) with soil depth

8 July 20 – Maturity

Crop Details

Table C8 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. Fibre quality was basis or above for most bales produced.

Table C8: 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

4. FIELD D - IRRIGATED

METHODS

Table D1: 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 D2: Fertiliser

			Nutrient Kg/ha									
Date	**Product**	**Product** 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 D3: 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 D4 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 D4: 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.

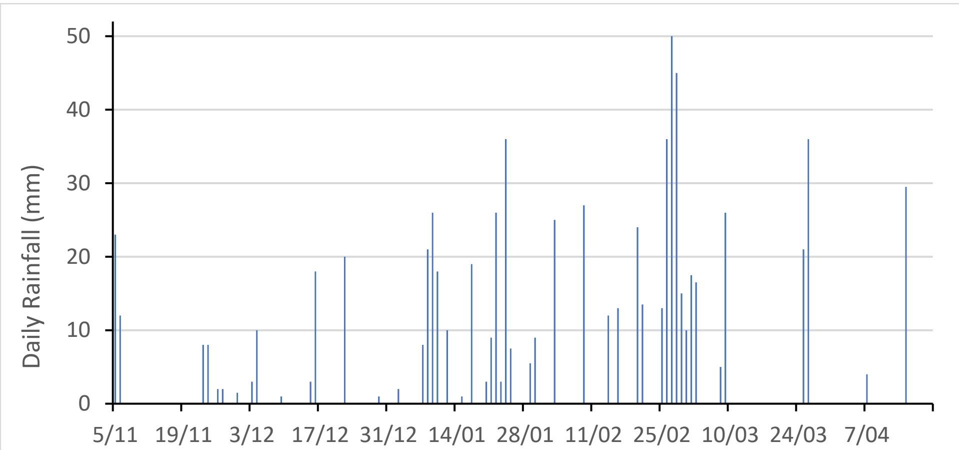

Fig. D1: Daily Rainfall

Temperature and solar radiation

Table D5: Average daily solar radiation and temperature

	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 D2 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

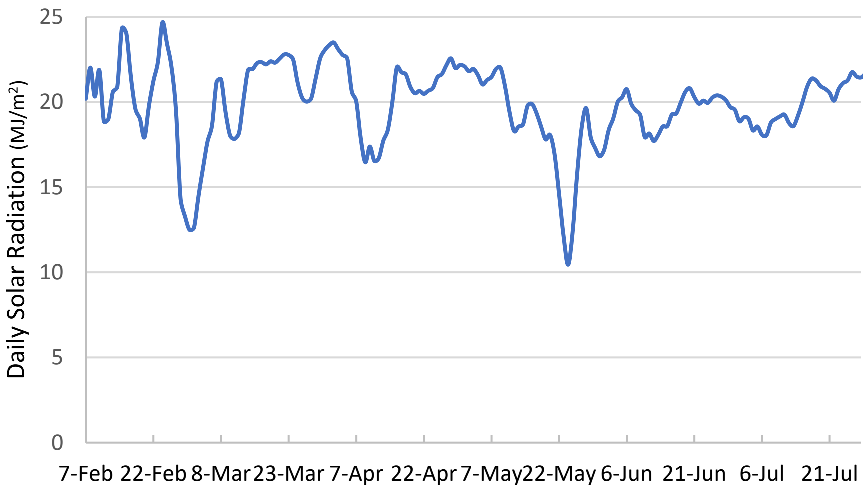

Fig. D2: Daily solar radiation for the growing season (shown as a 4 day moving average)

Mulch Cover Properties.

- Table D6 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 D6: Mulch Cover details

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

Soil cover at establishment, 6 February 2020

Soil Properties: Water, Nitrate and Organic Carbon.

Table D7 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 D7: 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	

8-May-2020: In-crop soil sampling

Table D8 shows:

- 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 D8: 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 D3 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.

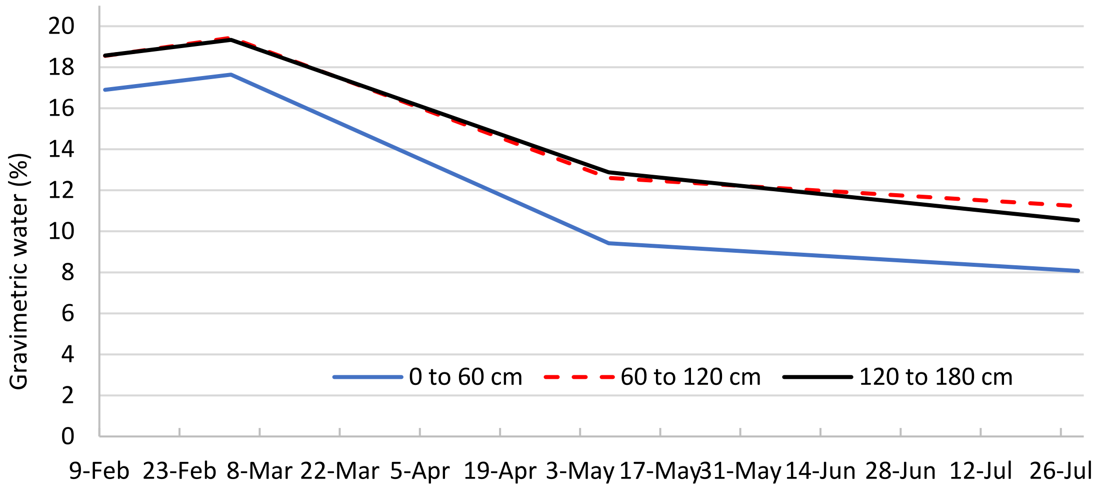

Fig. D3: Change in gravimetric soil water (%) with soil depth

Crop Details

- Table 9 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 fibre quality was good (basis or above).

Table D9: 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 fibre quality was basis or above.

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 E4 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 E4: Monthly rainfall volumes (mm) recorded at the field

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

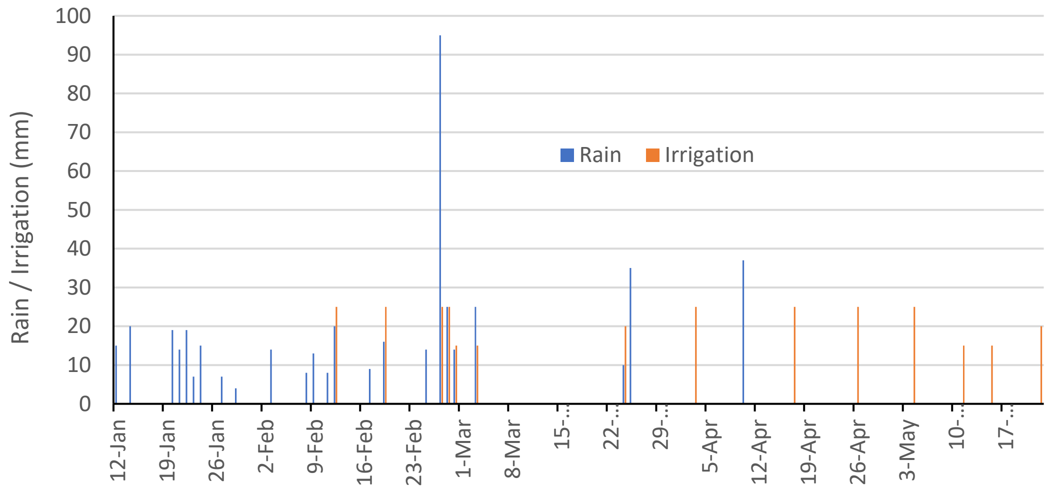

Fig. E1: Daily Rainfall and Irrigation volumes. Total rainfall post planting (6-Feb) was 463mm and total Irrigation 300 mm

Table E5: Average monthly temperatures compared to the long term average (LTA)

	Tmax		Tmin	
	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

- Fig. E2 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

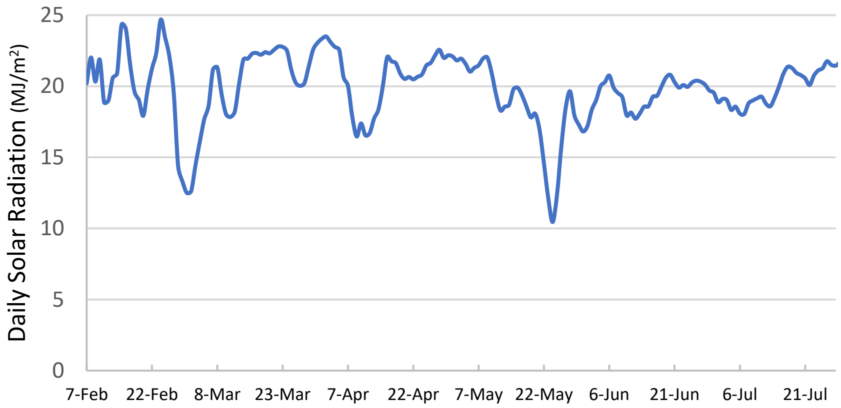

Fig. E2: Daily solar radiation for the growing season (shown as a 4 day moving average)

Mulch Cover Properties.

- Table E6 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 E6: 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

18-Feb-20: Crop establishment in Rhodes grass mulch.

Seasonal change in soil water, depth of water extraction and roots.

- Fig 3 shows soil water peaked on March 3 after which the crop removed soil water to 210 cm until maturity

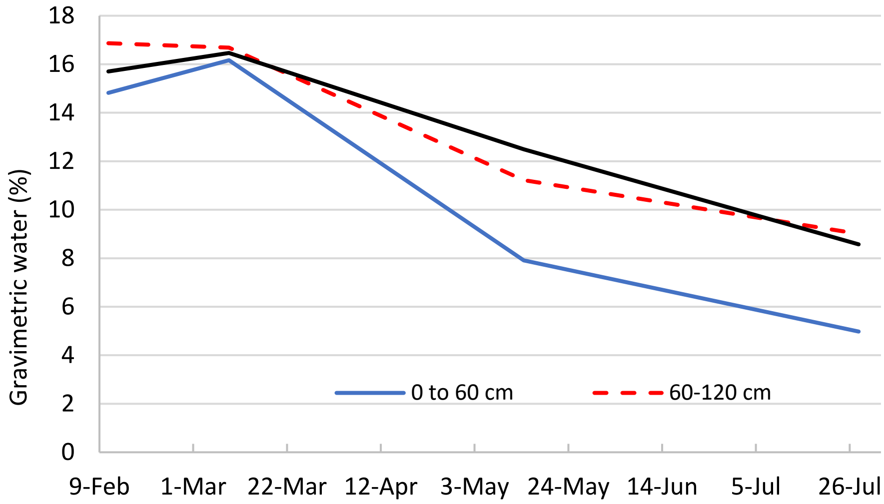

Fig. E3: Change in gravimetric soil water (%) with soil depth

- 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 E7 shows soil organic carbon and soil nitrate N near sowing were very low (18 kg N/ha) and typical for these soils.

Table E7: 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 E8 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 E8: 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 E9 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 E9: 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.

6. FIELD F - IRRIGATED

METHODS

Table F1: Field and crop details

Location /Area / Irrigation System	Tipperary / 100 ha / Pivot
Soil	Tippera - 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 F2 and F3.

Table F2: Fertiliser

			Nutrient Kg/ha									
Date	Product	Product 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 F3: 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 F4: 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 F5: Average daily solar radiation and temperature

	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

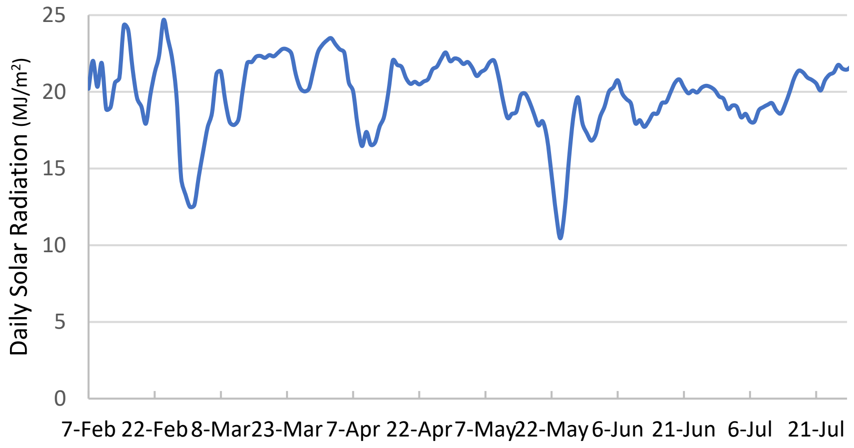

Fig. F1: Daily solar radiation for the growing season (shown as a 4 day moving average)

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)

Above: Mulch cover on 5-March-2020

Soil Properties: Water, Nitrate and Organic Carbon.

Table F6 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 F6: 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	

21 April 2020

Table F7 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 F7: 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 F2 shows soil water peaked on March 5, and despite irrigation, crop removal continued to a depth of 180 cm until picking.

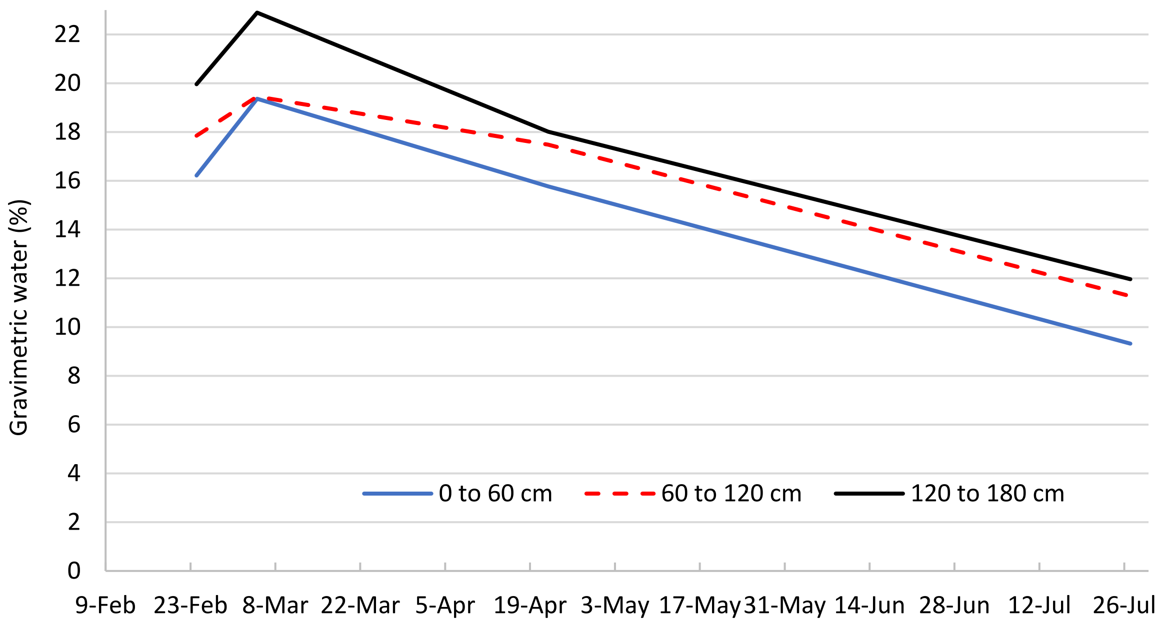

Fig. F2: Change in gravimetric soil water (%) with soil depth

Soil water sampling 5 March 2020

Crop Details

Table F8 shows:

- Maximum leaf area, plant height, node number and boll number were lowish for an irrigated crop planted mid wet season.
- Yield averaged 7 b/ha for the four datum areas picked and fibre quality was good (basis or above).

Table F8: 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.

ACKNOLDEGEMENTS

The project team appreciate the assistance provided by the growers, consultant agronomists and contractors at all fields monitored.

Final Results Report for CRCNA project A.2.1819004 potential for broad acre cropping in the NT: Maximising Rain Grown Cotton Seedling Establishment in the Northern Territory 2021 / 2022 season.

By Nick Hartley[1], Peter Shotton[1], Stephen Yeates[2], Tiemen Rhebergen[2] and Steve Frahm[3]
[1] NTDITT, [2] CSIRO, [3] Vanderfield-RDO

Key Findings:

- Evaluated were 5 planter configurations (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 / compaction from intense rainfall. Planting into two mulch scenarios were compared: 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 C on hot days. There was a low percentage of seed pinning into mulch in the conditions observed here when planting into 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 spraying out grass mulch after planting but prior to cotton emergence. Heavy rain that levelled the mulch exposing the previously shaded seedlings to extremely hot humid conditions.
- The rain grown cotton yields were reflected the in-crop rainfall after flowering. Where 50% of seedling death, due to early sowing larger branching cotton plants compensated and a good yield produced (5.7 b/ha).
- Future cotton establishment work needs 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* spp.).

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°50’S, 131°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.

Methods:

Two experiments on Oolloo soil type at Douglas Daly Research Farm). Experiment 1 (E1) was sown December 18th into green mulch and the 2nd 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.

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

Bubble coulters

Fluted coulter

Spiked press wheels

Rubber press wheels

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.

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.

Results

Climate:

Table 1 and Fig. 1 show:

- 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

- Total growing season rainfall E1 = 824 mm, E2 = 562
  -

Table 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)		Tmax (C°)		Tmin (C°)		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

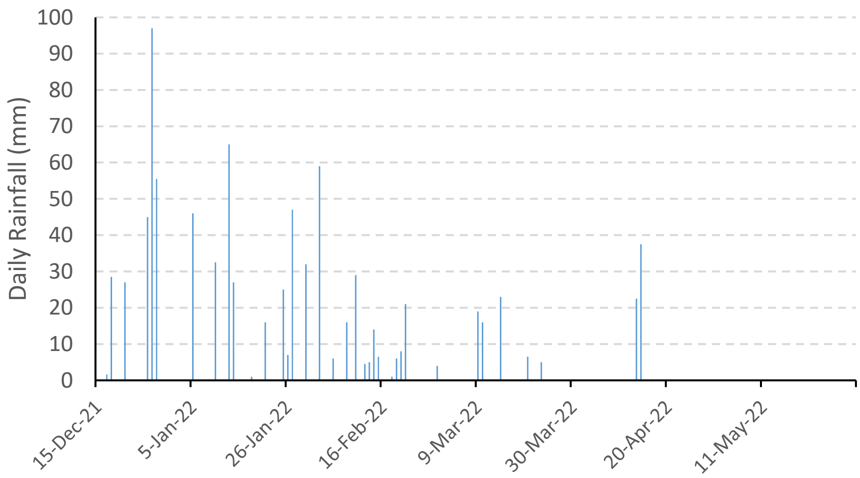

Fig. 1: *Daily rainfall volumes at the trial site*

Mulch Cover:

- Table 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 spp. 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 2: *Much cover dry weights and species composition.*

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


Measuring self-sown pasture cover prior to planting E1.

-

-

E2 showing dead mulch at crop establishment

Seedling Survival:

Fig. 2 shows:

- The E1 trial on 23-Dec-21, 5 days after sowing (DAS) seedling establishment met the target of 8 / m^2 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.

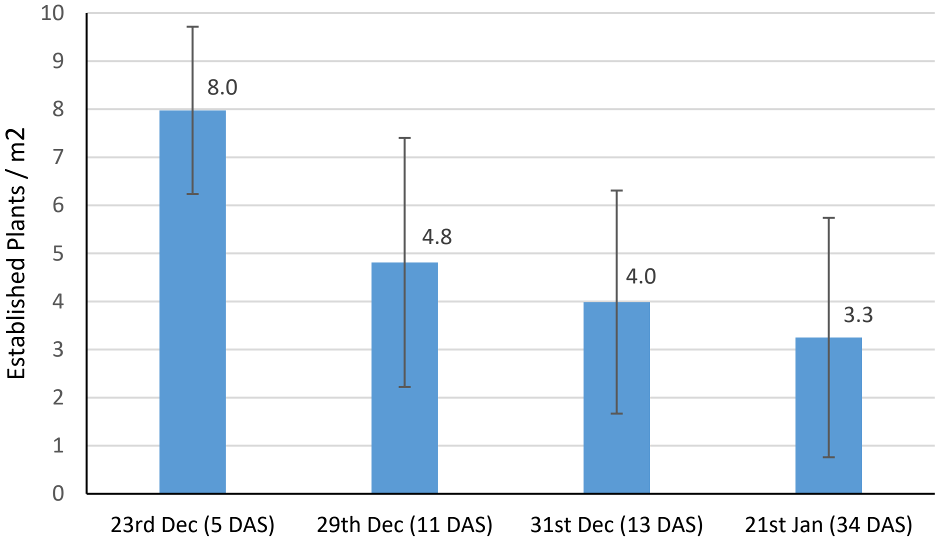

Fig. 2: The change in the number of surviving seedlings for the E1 trial from 23-Dec-21, 5 days after sowing (DAS) to 21-Jan-22. There was no significant difference between planter configurations, Bars are ± $lsd_{0.05}$ for each measurement date.

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.

The second trial, E2, 09/02/22

Plant line soil water:

- Soil water at the seed depth was high at planting of both trials (Table 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 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

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 3 shows daily maximum soil temperatures were at or above 40C° for 5 of the first 6 days after planting and never less than 37.5 C°. However, plant establishment was at the target 8 per m of row 5 days after sowing on the 23 December (Table 3)
- It is not clear why about 50% of seedlings perished between December 23 and 29 (Table 3) despite 3 days of cooler wet weather (Fig. 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.

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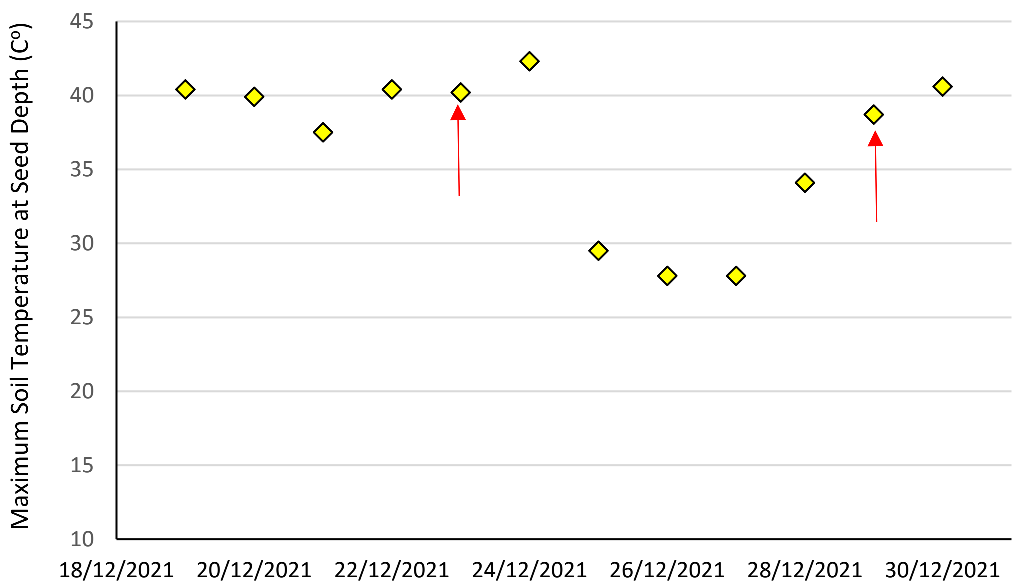

Fig 3: The daily maximum soil temperature at seed depth (~4cm) from 19/12/21 (1 day post planting) until 30/12/21. Arrows show the days when plant establishment was counted.

Trial E2

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

Yield and plant population at picking:

- Table 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 (Fig. 1).

Table 4: *Average trial seed cotton, lint yield and plant number / m^2 (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)

Trial E1 produced good yields despite a low and variable plant population (average 4.6 pl / m^2). 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.

E2 despite having an even target plant population of 8 pl/m^2, yield about 1 b/ha less than E1 due to later planting, 6 January, receiving significantly less rainfall during flowering and boll growth.

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

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 as 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).

Appendix: 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			

A full list of industry and scientific publications, presentations, extension activities and other outputs.

NB COVID-19 travel restrictions between March 2020 and December 2021 restricted travel between the three tropical jurisdictions preventing many intended activities. Stephen Yeates relocated to Darwin during the cotton seasons of 2021 and 2022 to ensure local cotton research could be implemented. This more effectively prevented trave to support north Queensland growers. Paul Grundy was able to fill this role.

Presentations / workshops etc

Cotton workshop on wet season cotton production 22 November 2018 at Ayr organised and presented by Paul Grundy and Stephen Yeates, twenty two farmers and consultants attended.

Stephen Yeates & Paul Grundy, Katherine Research Station field day 9 April 2019 > 100 attended.

Food Futures Road Show - Strathmore Station Cotton Field walk 30 April 2019 rain grown presentation by Stephen Yeates about 150 attended.

Australian Fertiliser Conference (Gold Coast) 5 September 2019 – Stephen Yeates "A cotton industry in northern Australia a new opportunity with some old challenges" (invited)

Cotton Research Conference, UNE, Armidale, NSW, 28 – 30 October 2019: "Cotton is going tropo: In addition to the obvious needs, where are the critical skills and behaviours?" by Stephen Yeates CSIRO (presenter), Paul Grundy QDAF, Penny Goldsmith ORDCO, Luke Mackay KAI.

IPM and "How Cotton Grows: Think like a cotton plant in the tropics" workshops were conducted at Kununurra WA and Douglas Daly NT during the week of March 2 to 6 2020 for farmers, agronomists, and researchers, about 25 attended at each site. The presenters and organisers for these workshops: Paul Grundy (DAF), Steve Yeates (CSIRO), Geoff Strickland (DPIRD), Helen Spafford (DPIRD), Ian Biggs (DPIR)

Stephen Yeates presented a cotton R&D update at the NT Farmers Association "Food Futures Roadshow" in Katherine 8-10 of September 2020 > 100 attended.

Douglas Daly NT on 28/10/20: Mulch management for cotton establishment workshop (Organised by Stephen Yeates and Rowena Eastick (NTNRM): Held at "Bindaroo Pastures" owned by Chris and Amanda Howie. Presentations were made by Chris Howie, Fergal O'Gara (local mulch farming expert), Stephen Yeates presented "Adapting conservation farming to tropical cotton production" (including pest management for mulch by Paul Grundy, (unable due to covid travel restrictions). Twenty two attended including 15 farmers. The key points from this workshop were included in the NTDITT "Northern Newsletter".

MT Isa 13 Nov 2020 – Stephen Yeates (invited) Opportunities and challenges for a viable northern cropping industry, Agforce Qld - Mount Isa Beef Forum and Feast 'Prosperity and Resilience in Future Shocks' about 200 attended.

Douglas Daly Research Farm NT Field Day on April 29, 2021, Stephen Yeates and Paul Grundy, NT Past work and the current research were presented at the rain grown cotton research field, 29 attended.

Julia Creek – 11 November 2021 -P Grundy (Presented) & Stephen Yeates "Considerations for Tropical Cotton Production'

Atherton Qld 18 November 2021. Steve Yeates & Paul Grundy presented "Considerations for Tropical Cotton' at the FNQ Sustainable Cropping Group forum.

NT Farmers Update, 25 November 2021, Douglas Daly Research Farm, Tiemen Rhebergen (CSIRO) & Collaborator Nick Hartley presented results of 2021 cotton trials, commercial crop monitoring and OZCOT-APSIM model validation.

NT Cotton Growers Association update, 28 February 2022. Douglas Daly Research Farm , Progress report on CRCNA project: Stephen Yeates – modelling, Peter Shotton (NTDITT) cotton establishment trial, 35 attended.

FNQ Sustainable Cropping Group forum, Mareeba Qld, 28 July 2022, Stephen Yeates – "R&D to learn Canopy Management during the tropical wet season".

Information/support

Provided by Stephen Yeates

Following a request from NT Famers Association president Paul Bourke, in lieu of the RD&E Cotton Grains Cattle funding EOI by CRCNA, I provided a written brief on key priorities for cotton grains and pastures in the region, March 2022.

On request from the consultant (Greg Monk) designing the irrigation channel for the Stage 3 expansion (17k ha) of the Ord River Irrigation area, I calculated monthly irrigation water demand by cotton based on previously completed research. Feb 2022

Bradfield Scheme Reassessment by the National Water Grid Authority. Stephen Yeates analysed of the climate near the area to be irrigated, recommended July as best planting date for cotton and reviewed yield & water use simulations made for Longreach, October – November 2020.

Provided past simulations of rain grown cotton yields in Flinders Catchment at Richmond to Marcus Scott a consultant representing a group of investors considering rain grown cotton north of Julia Creek. Unfortunately, there were not sufficient resources to provide the more detailed and local simulations, October 2020.

A proposed irrigation development project at Collinsville NQ where cotton was being considered. Attended 3 teleconferences coordinated by Bowen Utilities during July and August 2020, reviewed and provided recommendations on soil resource and crop suitability assessment reports. Concluded cost of land and dam development would exclude cotton and broadacre crops, then recommended they consider higher value crops such as lychees and bananas. Impact: the group accepted this recommendation and are now focused on these high value crops.

Provided climate suitability & tropical production information to Maryborough Sugar at Mareeba who are growing 400 ha of cotton 2019. Paul Grundy or Stephen Yeates visited on several occasions.

At the request of Tipperary Station in the NT, a review and 1st attempt at tailoring the southern B&P for the 'Top End" was made during August – September 2019. In addition to the tropical technical knowledge contributed by Stephen Yeates and Paul Grundy Cotton Australia, MyBMP and CRDC facilitated, reviewed and contributed. This exercise identified many large knowledge gaps in tropical Australia.

Over the life of this project the massive increase in tropical cotton from southern cotton growers and new northern growers was accompanied by demand for technical information, some examples follow:

Information in the form of NORpak- Burdekin, past trial reports, research publications, catchment studies, gross margin budgets and past NT soil and dryland cropping R&D has been provided to the following: Fergal O'Gara consultant agronomist NT, Andrew Philip NTFARMERS (many), Steve Buster consultant, Queensland cotton, Sam Simons consultant, James Hill consultant, Marcus Scott Consultant, Andrew Parks project manager, Ian Biggs researcher NT, Ken Fry farmer, Joanne Ellis and Ralph Addis for WA DPIRD minister. Telephone conversations have accompanied these requests.

Cotton science and monitoring skills

A focus of this project was the development of local science and technical skill as they didn't exist locally.

Support was provided to the NTDITT staff at Katherine in 2018 & 2019 (written, phone and face to face) the design and measurements (include field instruction) required for this seasons field trial program at Katherine Research Station. Three visits were made March, April and June 2019. The April visit included presentations at their field day by Stephen Yeates and Paul Grundy.

Support continued the after the commencement of the CRCNA collaboration commenced in late 2019 until project end in 2022. With support also required at the Ord and north Queensland. CSIRO senior technical office Jenny Stanford compiled, wrote and circulated a book titled "Guide to cotton plant and soil measurements". The Guide was regularly updated during 2020 and 2021 and is attached to this report.

Publications

Tropical Cotton Production: Considerations for Northern Cotton Growers (2020) – distributed by email and in www.acresofopportunity.com.au

Yeates SJ and Poulton PL (2019). Determining Dryland cotton yield potential in the NT: Preliminary climate assessment and yield simulation. Report to NT Farmers Association, Queensland Cotton and the Cotton Research and Development Corporation. CSIRO Agriculture and Food. Distributed by email and in www.acresofopportunity.com.au

Report for NT Farmers Association (Yeates SJ) "Dry season cotton near Adelaide River, Climatic considerations for dry season cotton", March 2019.

Contributed to all additions of the Northern Newsletter - www.acresofopportunity.com.au

Guide to cotton plant and soil measurements 2021. Compiled by Jenny Stanford, CSIRO, Townsville, Qld.

Part 4 – Summary for public release

This summary is designed to provide a short overview of the project for all interested parties. It will be published on Inside Cotton, CRDC's digital repository, along with the full final report (if suitable for public release). The summary may also be published on grow[AG.], a collaborative platform that showcases Australian agrifood research, development, and extension projects that are current or have been completed since 1 July 2018. Please complete all fields, ensuring that this exceeds no more than two pages.

<table>
<tr><th>Project title:</th><th colspan="2">Error! Reference source not found.</th></tr>
<tr><td rowspan="7">Project details:</td><td>CRDC project ID:</td><td>Error! Reference source not found.</td></tr>
<tr><td>CRDC goal:</td><td>3. Build adaptive capacity of the cotton industry</td></tr>
<tr><td>CRDC key focus area:</td><td>1.1 Optimised farming systems</td></tr>
<tr><td>Principal researcher:</td><td>Dr Stephen Yeates, Principal Research Scientist</td></tr>
<tr><td>Organisation:</td><td>Error! Reference source not found.</td></tr>
<tr><td>Start date:</td><td>01_October_2018</td></tr>
<tr><td>End date:</td><td>30_September_2022</td></tr>
<tr><td>Objectives</td><td colspan="2">To provide science leadership to support for cotton evaluation and expansion into northern Australia.
To enhance the technical skills base for northern cotton production.
To establish partnerships with local agencies and commercial investors to
1. build an understanding short and long term production and risks, identify key management practices and fine tune identification of suitable soil resources.
2. Responded to any emerging R&D issues.</td></tr>
<tr><td>Background</td><td colspan="2">Investor interest in cotton as a broadacre base crop in northern Australia is very high. This project builds on past R&D that initially addressed known biophysical challenges to irrigated cotton production in the tropics, such as sustainable pest management, preventing N losses during the wet season and management options to minimise the impact of extreme climatic events. There is a need to assess yield potential and climatic risk reflects the broad range of potential new regions and any proposed developments are based on the best available science for cotton. With rain grown cotton evaluated for the first time since the 1960's in much of northern Australia. A key question to guide industry development and to support the establishment of local gins is what the area of suitable soils in the various regions is, that can be developed for (rainfed) cotton, and the expected variability in annual production by region.
A local technical skills base to support a northern cotton industry needs to be developed.</td></tr>
<tr><td>Research activities</td><td colspan="2">Research activities were in two forms
Delivery of resources, past and new information to support to sport the new growers, consultants, research personal and government departments approving / supporting investments.</td></tr>
</table>

	Activities: Industry publications, workshops, the northern newsletter (listed below) and 1 to 1 meetings. 2. *Targeted field research to address the known objectives and respond to new questions.* Four activities were conducted "NT rain grown cotton suitability, model calibration, validation and application" and "Monitoring of commercial cottonfields 2019/20 wet season" were planned from the onset. The "Cotton Row Spacing Comparisons 2020 & 2021 (rain grown) and " Maximising cotton seedling establishment in the Northern Territory 2021/2022" were in response to requests from growers and a serious problem for growers respectively.
Outputs	*Reports, workshop slides / notes, other presentations and publications (see below). Future scientific papers.* NT rain grown cotton suitability modelling found: Soils with high availability of water to cotton is critical, the simulated yield loss of 14 to 26% for the soils with lower soil water. Timely planting significantly increased median yield, with yield penalties of 17 to 40% for planting after 15 January. A cotton suitability modelling paper for possible NT rain grown regions is planned.
Impacts	The need for zero tillage + protective soil mulch for reliable rain grown cotton establishment via workshops and collation of past information was very effective for new rain grow growers as the majority have attempted and persisted with zero tillage. For rain grown cotton: Awareness of the need to identify soils with greatest soil water, created by presentations of modelling study analysis. Seedling establishment studies confirmed the short term need for more research.
Key publications	Tropical Cotton Production: Considerations for Northern Cotton Growers (2020) – distributed by email and in www.acresofopportunity.com.au Yeates SJ and Poulton PL (2019). Determining Dryland cotton yield potential in the NT: Preliminary climate assessment and yield simulation. Report to NT Farmers Association, Queensland Cotton and the Cotton Research and Development Corporation. CSIRO Agriculture and Food. Distributed by email and in www.acresofopportunity.com.au Report for NT Farmers Association (Yeates SJ) "Dry season cotton near Adelaide River, Climatic considerations for dry season cotton", March 2019. Contributed to all additions of the Northern Newsletter - www.acresofopportunity.com.au Guide to cotton plant and soil measurements 2021. Compiled by Jenny Stanford, CSIRO, Townsville, Qld.