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Preliminary Determination of Dryland Cotton Yield Potential in the NT

Climate assessment and yield simulation

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Acknowledgments

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1 Introduction

Growing dryland crops in the tropical 'Top End' is very different to traditional summer cropping areas in south eastern Australia. The approach to cropping is similar to the drier Mediterranean winter cropping areas of south Australia and western Australia except that cropping occurs in the summer in the tropics.

That is:

- There is a clearly defined wet and dry season
- The crop must be grown using in-crop rainfall with minimal reliance on stored soil water as soils are well drained mostly with low moisture holding capacity; not heavy self-mulching clays that can store water over a fallow period. By the end of the dry season (October – November) the soil has almost no plant available moisture.
- Early in the wet season rainfall is extremely variable and air and soil temperatures are very high.
- The optimal sowing window is usually tight as it is a balance between sowing early enough to reliably establish a crop and capture as much in-crop rainfall as possible during the wet season. While not planting too early and expose maturing / open bolls to pre-picking rain which will downgrade fibre colour and can reduce yield via boll rot.
- Yields usually decline rapidly as planting is delayed after the optimal window. Zero-till systems with good soil mulch cover increase the number of planting days within the optimal window.
- Cotton yield is largely determined by boll number (70%) which is proportional to the length of the growing season. The other contributor to yield (30%) is boll weight which requires favourable climatic conditions after flowering (water, solar radiation, temperature).
- Cotton requires Nitrogen and in the absence of other stresses yield is proportional to the amount of N taken up by the crop in the first 90 days of growth. N nutrition needs to be managed in a similar way to other wet season crops. In-crop application is usually the most efficient for wet season grown cotton with application most effective between 30 and 55 days after planting.

Soil Issues

Two main soil groups suitable for cropping occur in the Top End and Sturt Plateau; Tippera clay loams and Blain sandy loams these have the following characteristics:

- Low inherent fertility particularly N, P and many micro nutrients. Organic carbon is also low.
- Mostly low plant available water (80 to 125 mm to 160 cm) although some blain soils are higher being deep (>3m) with a clay loam texture below 1m. The better dryland cotton areas in NSW and Qld have self-mulching clays with 250 to 350 mm of plant available water.
- High susceptibility to surface crusting after ploughing.
- Easily erodible particularly the Blain.
- High soil temperatures will kill establishing seedlings. Surface much cover is the best protection.
- Nitrogen as NO_3^- is easily leached below the root zone or lost in runoff water.

Clay Soils: Where the climate could be suitable for cotton significant areas of heavy clays occur in the Bains and Roper catchments and the Barkley Tableland. Experience at the Ord and Burdekin has demonstrated limited wet season trafficability and water logging are major constraints of clay soils.

Clay soils are suited to irrigated dry season cropping provided the growing season is long enough to permit reliable planting when soil is accessible late in the wet season (March to May depending on the location and season) while ensuring maturity avoids rain at picking (September to November). Small volumes of rain on open bolls during the hot build up period (October – November) will discolour lint often resulting in large price discounts. Cold night temperatures (<12^{o} C) can down grade fibre quality, reduce yield and delay maturity. The extent of these impacts depends on the number of cold nights and the stage of fruiting.

2 Selection of the wet season planting window for dryland cotton

- Assuming average temperatures, cotton planted in the wet season will require at least 100 days to produce its first open boll then depending on the flowering period will continue to grow and open bolls for about a month provided soil water is available. Planting too early in the wet season could increase growing season length but increase the risk poor crop establishment and rain at maturity.

- Hence the length of the growing season for dryland cotton in the NT will depend on the duration of the wet season following planting and the amount of soil available water to finish boll growth after the 1st boll has matured.

- Many top-end soils hold only 80 to 125 mm of plant available water in the root zone. The end of the wet season occurs from mid-March to mid-April in most localities. An actively growing crop grown on a soil providing 90 mm of water will extract approximately 6 mm of water per day when actively growing, hence will begin water stress avoidance in 8 to 10 days and sever stress after another 15 days!

The likely best planting windows for cotton at 4 locations in the NT was identified by:

1) Calculating thermal time values (Degree day sums) derived at the Burdekin to predict the date of critical crop stages.

2) Calculating half monthly rainfall variability and comparing this with growth stages for different planting windows to define the best balance of wet or dry conditions for crop establishment, yield, boll rots or fibre discoloration of maturing bolls (see appendix for more detail).

2.1 Tipperary and Douglas Daly

Figure 1 shows:

- Half monthly rainfall is extremely variable, particularly from late January to early March.

- Expected rainfall declines rapidly from mid-March although remains highly variable in late March.

- Boll opening needs to commence in late March to early April to reliably avoid large rainfall events on maturing bolls.

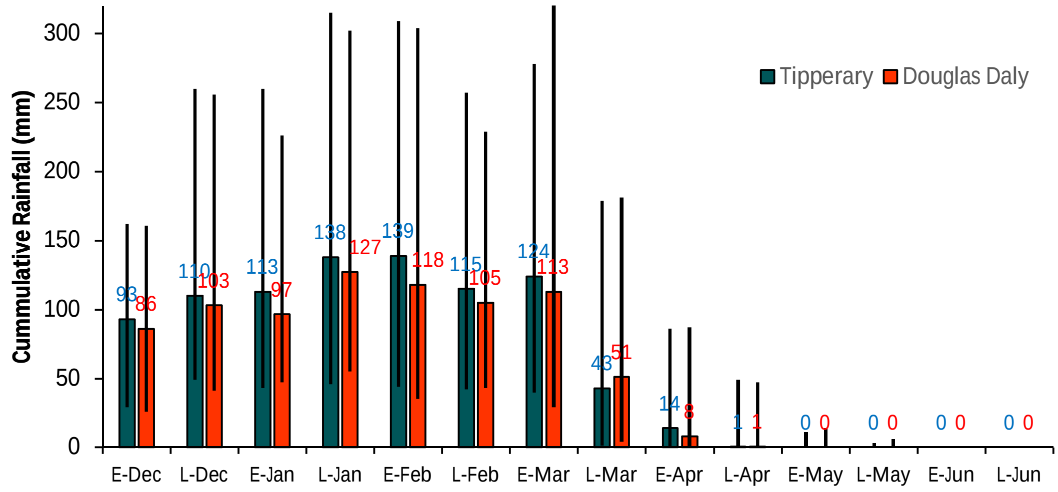

Fig 1: Half monthly rainfall for Tipperary and Douglas Daly. Columns are 50% of seasons bars show the range in 10 to 90% of seasons.

Table 1 shows:

- Planting 1 to 15 December will expose a cotton crop to large volumes of rain during early boll maturity (mid–March).
- Planting in late-December to mid-January will provide rain during flowering with a lower risk of rain at maturity.
- Planting in early February avoids rain on maturing bolls but greatly reduces the likelihood of rainfall during flowering and boll growth risking lower yield. A soil with higher than average plant available water will be required to reliably produce acceptable yields when sown at this time.

Table 1: Occurrence of key growth stages at Tipperary and Douglas Daly and possibly of climate induced fruit shedding, boll rot, fibre colour down grade for each sowing date. NB dates to last flower and defoliation can vary by up to 2 weeks due fruit shedding and temperature variation. Green shading indicates the likely optimal planting window.

Sow Date	1st Square	1st Flower	Last Flower	1st Open Boll	Defoliation
1st Dec	L-Dec	M-Jan	M-Feb	E-Mar	E-Apr
15th Dec	M-Jan	E-Feb	E-Mar	M-Mar	M-Apr
1st Jan	L-Jan	M-Feb	M-Mar	E-Apr	E-May
15th Jan	M-Feb	E-Mar	E-Apr	L-Apr	L-May
1st Feb	L-Feb	L-Mar	L-Apr	M-May	L-Jun
14th Feb	M-Mar	E-April	E-May	L-May	E-Jul
Fruit shedding	Shedding & Boll rot	Colour Grade & boll rot	**Colour Grade**		

2.2 Katherine and Larrimah

Figure 2 shows:

- The rainfall pattern is similar to Tipperary and Douglas Daly with lower rainfall volumes per half month.
- Rainfall variability is extreme between late December and late March.
- Lower rainfall volumes will increase the risk of within season water stress and reduce the risk of boll rot and fibre colour down grade due to prolonged rainfall near maturity.

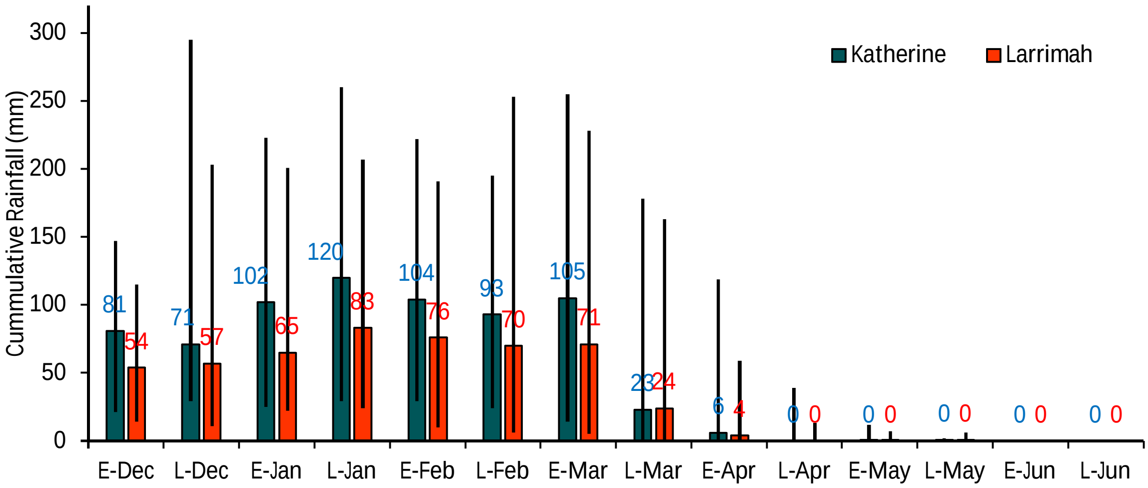

Fig 2: Half monthly rainfall for Katherine and Larrimah. Columns are 50% of seasons bars show the range in 10 to 90% of seasons.

Table 2 shows:

- The planting window will be similar to Tipperary and Douglas Daly with the greater likelihood of water stress and high temperature reducing planting opportunities in mid-December and yield when planting occurs on or after mid-January.
- Fibre discoloration and boll rots at or near boll maturity will be less likely in late March and early April.

Table 2: Occurrence of key growth stages at Katherine and Larrimah and possibly of climate induced fruit shedding, boll rot, fibre colour down grade for each sowing date. NB dates to last flower and defoliation can vary by up to two weeks due fruit shedding and temperature variation. Green shading indicates the likely optimal planting window.

Sow Date	1st Square	1st Flower	Last Flower	1st Open Boll	Defoliation
1st Dec	L-Dec	M-Jan	M-Feb	E-Mar	E-Apr
15th Dec	M-Jan	E-Feb	E-Mar	M-Mar	M-Apr
1st Jan	L-Jan	M-Feb	M-Mar	E-Apr	E-May
15th Jan	M-Feb	E-Mar	E-Apr	L-Apr	L-May
1st Feb	L-Feb	M-Mar	M-Apr	E-May	M-Jun
14th Feb	M-Mar	E-April	E-May	L-May	M-Jul
Fruit shedding	Shedding & Boll rot	Colour Grade & boll rot	**Colour Grade**		

2.3 Other Climatic Challenges

2.3.1 Seasonal Solar Radiation

Solar radiation provides the energy for photosynthesis and crop growth. Compared to St George, a high yielding growing area in Qld, the Top-End recieves about 13 to 16 % less solar radiation per day during flowering and boll filling due to latitude and wet season cloud cover (Fig. 3). Based on experience with January sown irrigated cotton at the Burdekin the deficit in solar radiation is likely to reduce yield potential compared with St George. It is probable the potential yield of dryland cotton will be less affected by this seasonal solar radiation deficit as other factors will limit yield with greater frequency e.g. water availability.

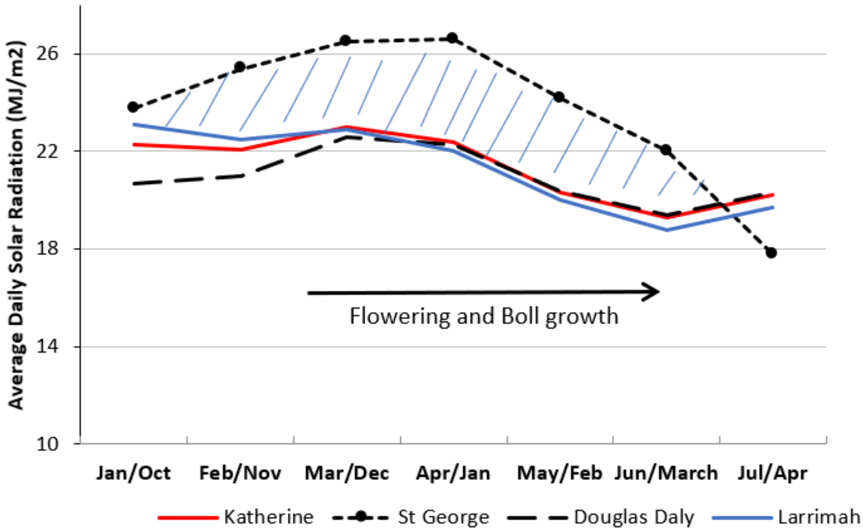

Fig 3: Comparison between average daily solar radiation between St George a high yielding temperate climate growing season (October to April) and Douglas Daly, Katherine and tropical season cotton (January – July). The shaded area represents the difference in solar radiation between the tropical and temperate sites during the flowering and boll filling period.

2.3.2 The within season variability of solar radiation

Figure 4 shows from late January to early March half monthly variability of solar radiation is very high and median solar radiation is lowest. This variability has the potential to disrupt fruit setting during flowering and the balance between vegetative and reproductive growth at this time in dryland and irrigated crops. Yield reductions averaging by 15 to 35% were measured in the Burdekin when solar radiation has been reduced by 30% to 60% for 14 days late in flowering. Crop management may need to adapt to the changing growth and fruit setting. Due to declining water availability dryland crops will be less capable of capitalising on the improved radiation environment from later March into April than irrigated crops.

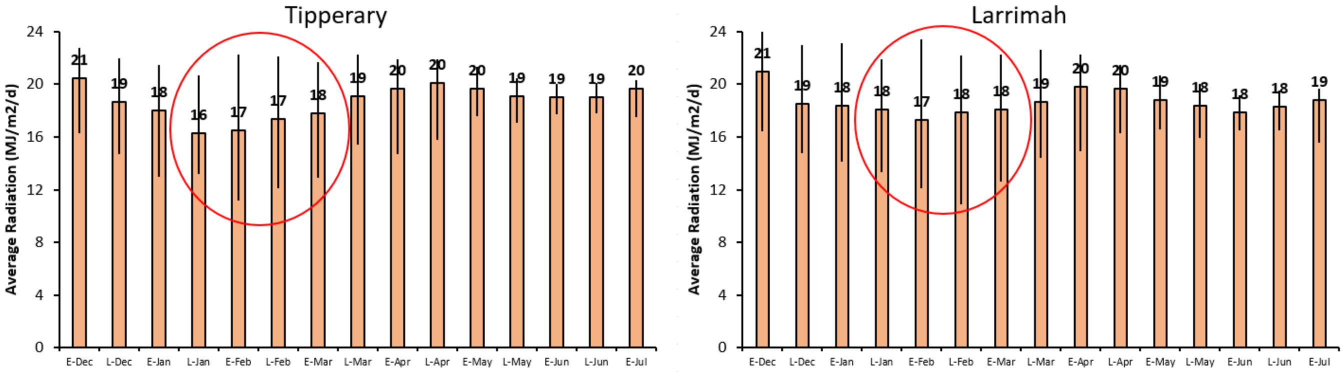

Fig 4: Median half monthly solar radiation, error bars show range in 10 to 90% of seasons.

2.3.3 Fibre quality

The key fibre properties length, strength and micronaire can be discounted from preference values by sever water stress during fibre expansion and growth.

3 Preliminarily simulation of climate soil and management effects on possible dryland cotton yields in the NT

The cotton simulation model APSIM-OZCOT (test version 7.9 with tropical enhancements) was used to predict dryland cotton yield grown at Tipperary, Douglas Daly, Katherine and Larrimah using climatic records for the period 1957 to 2019. Cotton was grown on the Tippera and Blain soil groups common to the region. Soils within each group had been parameterised for the model in the past. The effect of sowing date, nitrogen fertiliser and soil surface management and plant available soil water on median yield and its variability was simulated. See the Appendix for more details.

It should be noted the APSIM-OZCOT model has not been validated against a dryland cotton crop grown in the NT. Validation will commence in the 2020 season.

- The model assumes pests and weeds do not reduce yield, nutrients other than N are not limiting and there is an even plant stand.
- The model needs to be validated locally to have good confidence in the response to N fertiliser and soil water availability in this environment as the model was developed at Narrabri NSW.
- Characterisation of local soils for the model is essential for accurate simulation. Some of the key arable Tippera and Blain soil groups have satisfactory characterisation; more are needed.

3.1 Sowing date response on typical Tippera and Blain soils.

This analysis indicates likely yield variability given the same pre planting starting conditions each season. That is what could next seasons' crop yield?

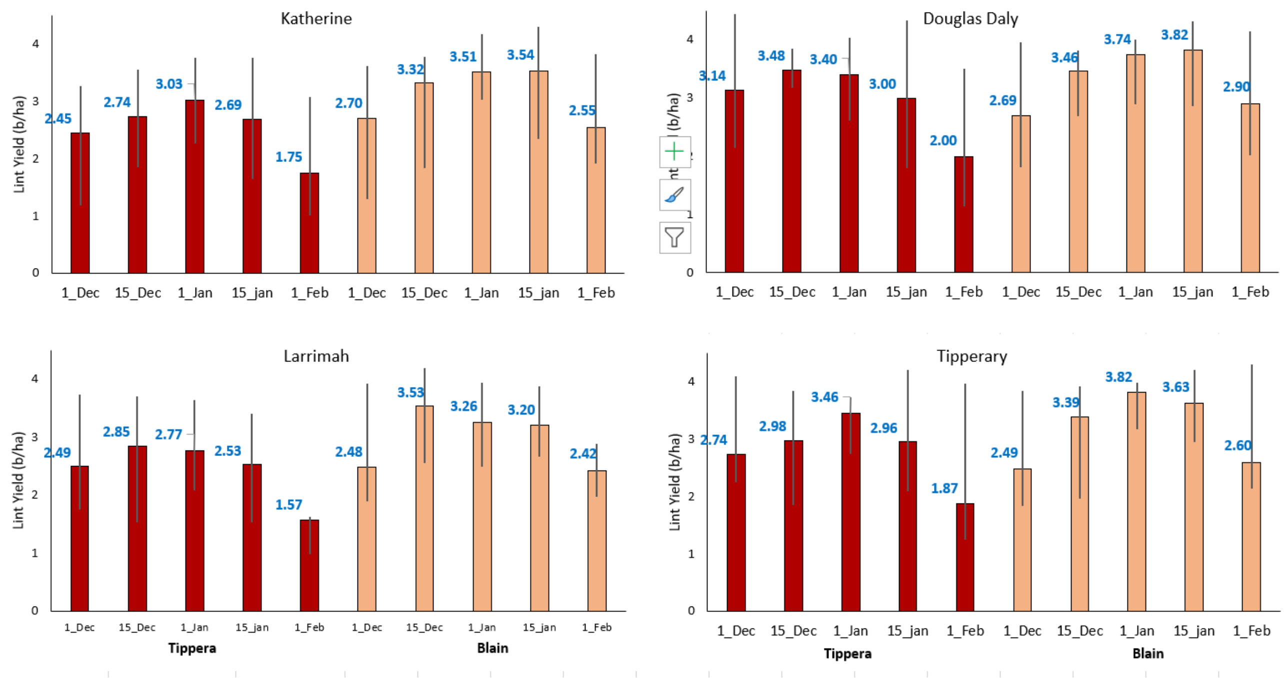

Fig 5: Simulated (APSIM-OZCOT model) median cotton yields for 1957 to 2019 and their range (bars = 20 to 80% of seasons), planted within a half monthly window commencing at the date sown for the seasons when soil water permitted (not too dry) for typical Tippera and Blain soils having 122mm and 138 mm available soil water. A 2 t/ha legume (stylo) stubble retained from the previous season, organic carbon and soil available N were low and typical for this scenario is reset on September 1 each year. Nitrogen fertiliser 100 kg N/ha was applied 50:50 at sowing (details in Appendix).

Key points:

- Planting from late-December to mid – January produced the highest yields. With the Blain greater than the Tippera soil due to deeper rooting and higher available soil water.
- Crops planted in February simply ran out of water in the majority of seasons.
- As patchy stands or replanting due to high soil temperatures and soil crusting are not accounted for in this analysis yields for December planted crops are likely to be an over-estimate. Future research aims to incorporate poor establishment.
- This analysis does not account for the number of planting days within each sowing window as the yields simulated in Fig 5 are for a crop planted on the first day within each window when planting was possible.
- The above yields reflect one possible but not the only scenario for soil available water, nitrogen supply (soil and fertiliser) and previous crop and soil cover effects.

3.2 Nitrogen rate.

These simulations ask the question if I plant in the favourable early January window on the same soil and crop/ soil surface-cover as the previous analysis how much N fertiliser is optimal? Figure 6 shows simulated yields for dryland cotton planted between the 1st and 15th of January with nitrogen fertiliser is split 50:50 between planting and near first flower (March 12). See Appendix A for details.

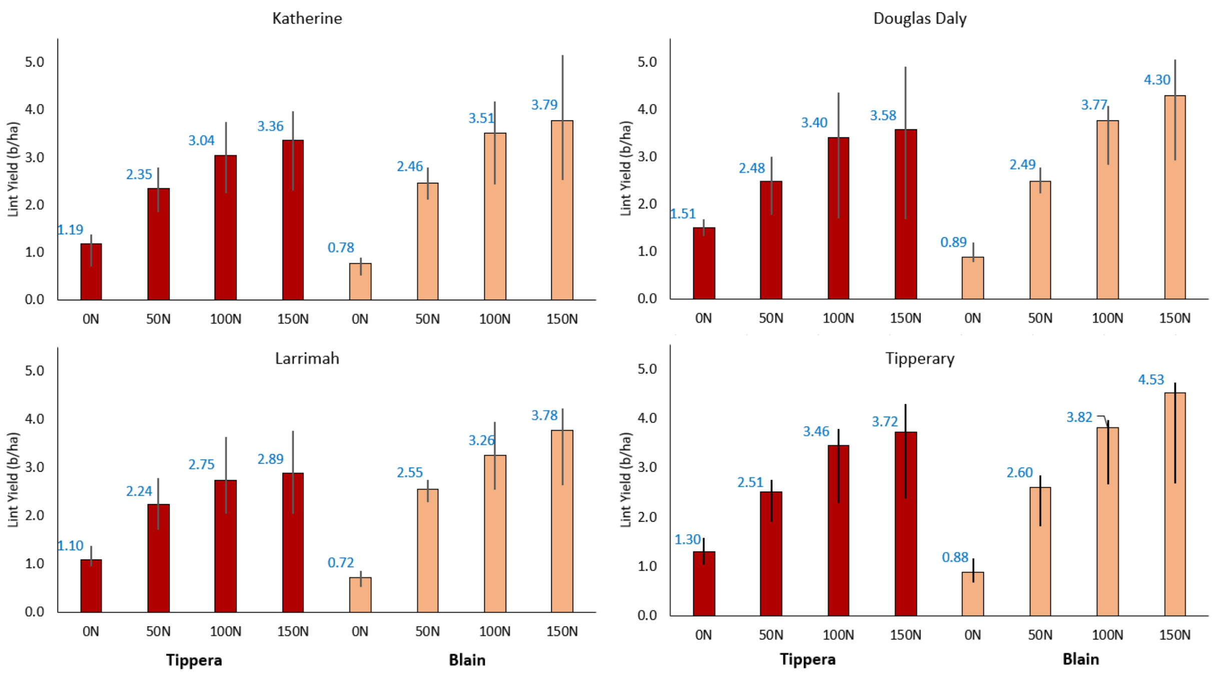

Fig 6: Simulated dryland cotton yields for nitrogen fertiliser spilt 50:50 between at sowing and mid- February range (bars = 20 to 80% of seasons). Planting was between January 1 and 15. A 2 t/ha legume (stylo) stubble retained from the previous season with soil available N low and typical for this scenario; available soil water was 122mm and 138 mm for Tippera and Blain respectively. (see Appendix for details).

Key points:

- At all locations and soils the unfertilised soil is very deficient in available nitrogen in this management scenario.
- Applying 150 kg N / ha gave a marginal yield benefit over 100 kg/ha. Clearly water and climate factors limit the yield potential.
- Cotton grows deeper roots on the blain soil due to its porous texture, this enables uptake of nitrogen leached deeper in the profile by wet season rainfall.
- This analysis does not account for the number of planting days within each sowing window as the yields simulated in Fig 6 are for a crop planted on the first day within each window when planting was possible.

3.3 Available soil water

Plant available water for some variants of the Tippera and Blain soil groups was measured previously at Katherine and Douglas Daly for sorghum and other grain crops. Figure 7 compares dryland cotton yield when planted between 1 to 15 January using known upper and lower plant available water for sorghum (cotton is similar) for these soil types. Some variants of the Blain soil are known the have a greater clay content at depth and higher plant available water to deep rooted crops such as cotton but have not been characterised for plant available water, so a soil was created for this analysis as a comparison (Blain 160mm).

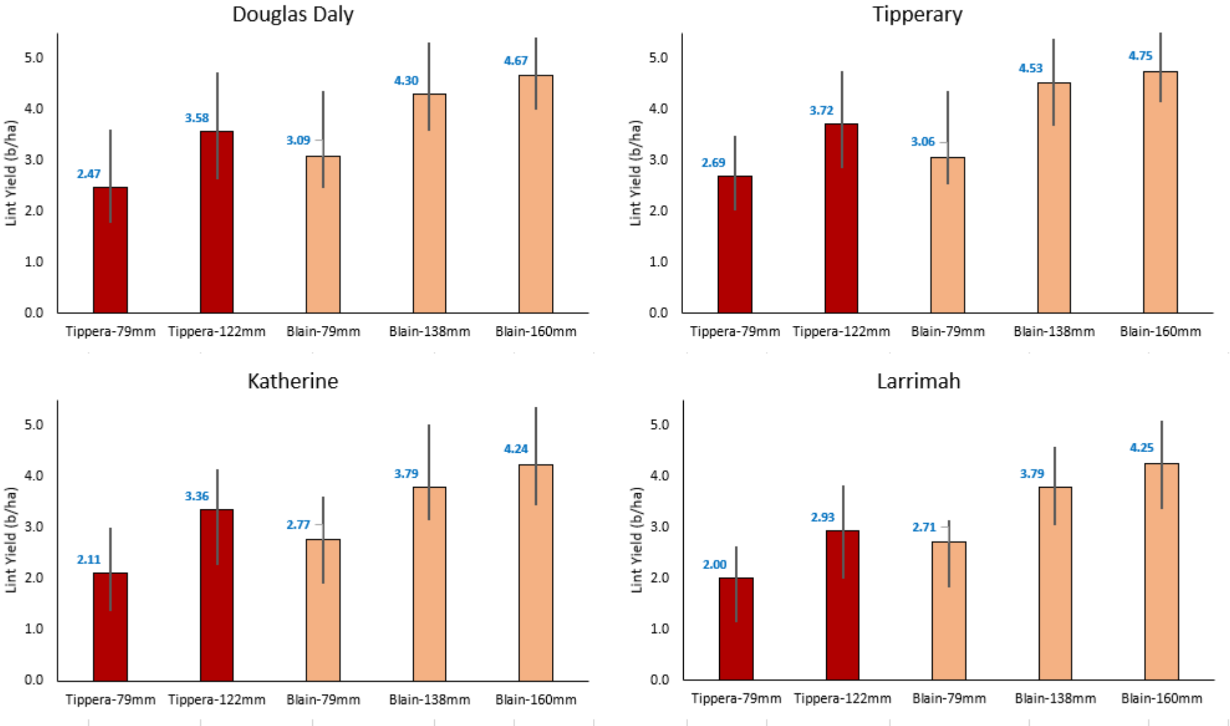

Fig 7: simulated cotton yields grown on the known variation in plant available soil water for Tippera (79 to 122 mm) and Blain (79 to 138 mm) soils and a hypothetical Blain with 160 mm available due greater clay content at depth range (bars = 20 to 80% of seasons). Planting was in early January. Nitrogen was not limiting i.e. soil organic carbon, available NO_3 / NH_4 as per Fig 1, 150 kg/ha N fertiliser split between sowing and squaring with 2 t/ha of legume much cover from previous wet season (more details in Appendix).

Key points:

- As expected yields and their variability reflect the available soil water and frequency, volume and timing of in-crop rainfall at each site (as shown in Fig 7).
- The scenario presented here does not include limitations to soil water infiltration observed for soil variants prone to surface crusting or where crusting is induced by management e.g. excessive cultivation.
- This analysis highlights the importance of selecting soils with the highest plant available soil water for cotton and are also trafficable in the wet season.

3.4 Tillage and soil surface cover

Research and commercial practice on dryland grain crops in the NT during the 1990's clearly demonstrated the huge benefit of zero or reduced tillage into mulch cover provided any nitrogen tie up by non-leguminous mulches could be managed. The key benefits where a greater number of planting days within the optimal window, higher yields in dry years, lower soil temperatures, reduced soil crusting, greater infiltration of rainfall and slower drying of the soil surface when the crop is young.

Figure 8 compares the amount of mulch cover, the type of mulch cover, the addition of nitrogen fertiliser, available soil water and the impact of soil crusting on dryland cotton yield at Katherine and Douglas Daly. It does not consider changes in the number of planting days.

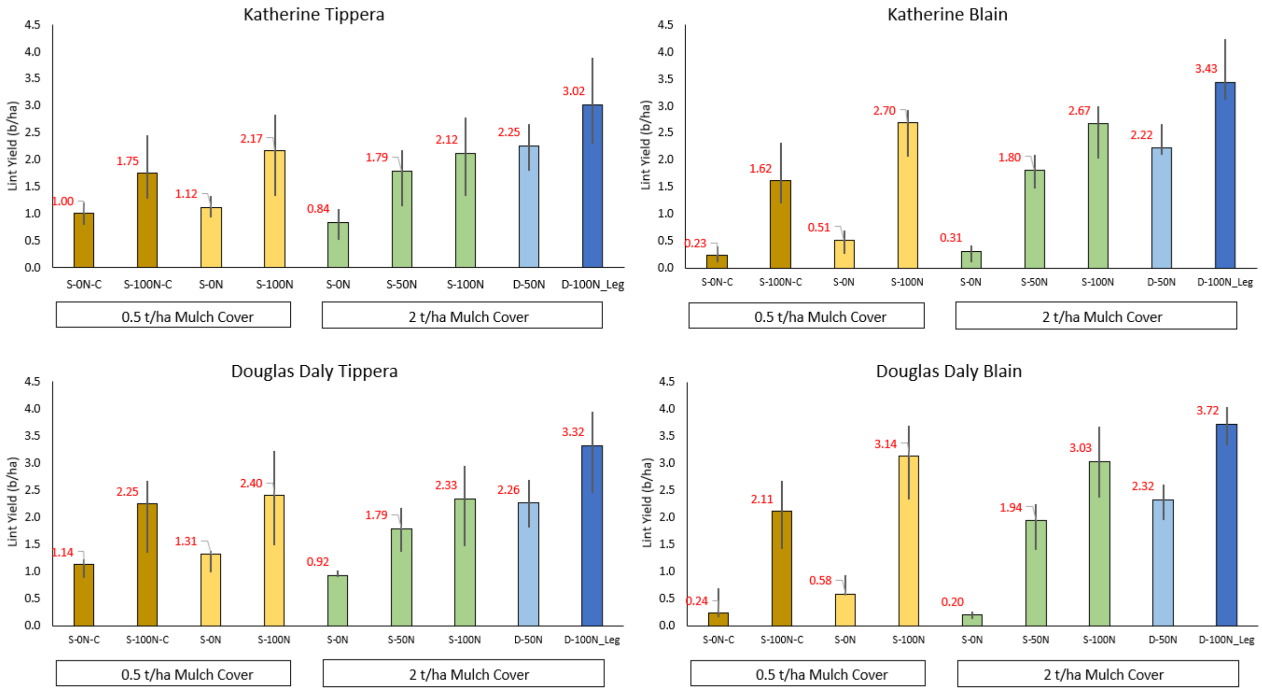

Fig. 8: Simulated dryland cotton yields on shallow (**S**) 80mm and deep (**D**) 124 to 138 mm available soil water Tippera and Blain soils with 0.5 or 2 t/ha of sorghum mulch cover, zero to 100 kg/ha of N fertiliser and a hypothetical deep blain soil with 2 t/ha of legume pasture as cover. Surface crusting (**C**) that slows water infiltration is included where there is low surface cover of sorghum (0.5 t/ha). Bars show range 20 to 80% of seasons. See Appendix for more details.

Key points:

- This analysis is a demonstration of the possible impact soil surface management and nitrogen availability could have on dryland cotton yield.
- Mulches high in carbon and low in nitrogen such as sorghum and grass pastures tie up nitrogen while decomposing, hence the lower yield for the same nitrogen fertiliser and soil than in Fig 8.
- Surface crusting will exacerbate yield reductions when it is dryer than average, any rainfall is sporadic and intense, and the crop is young. The model needs to be validated for these scenarios to have good confidence in the responses shown in Fig. 8.

4 Conclusions

- The planting window for dryland cotton that is most likely to balance yield with avoidance of rain damage to maturing cotton was mid-December to mid-January.

- However, when planted within the optimal window the median simulated dryland yield varied between 1 and 5 bales / ha; the range due to differences in available water between soils, soil nitrogen availability including N fertiliser management, and the amount and type of soil much cover.

- When a legume mulch contributed 20 to 30 kg N/ha to nitrogen supply yield was maximised by applying 100 kg/ha of N split 50:50 between sowing and 30 days after sowing. Applying 150 kg N/ha marginally improved yields as other factors were limiting (water, solar radiation).

- This analysis demonstrated the need to target soils with higher water availability for dryland cotton production.

- The model could not simulate poor establishment due to high soil temperatures, pest and weed impacts, and deficiencies in nutrients other than nitrogen.

- The APSIM-OZCOT model has not been validated against a dryland cotton crop grown in the NT. Validation will commence in the 2020 season.

Appendix A Methodology

A.1 Growth Stage prediction and climatic variability analysis

Predictions for date of 1st square, 1st flower and 1st open boll were made using degree day sums developed for cotton grown in the wet season at the Burdekin (Grundy et al. 2012) and calculated from long term average temperatures for each location.

Time of last (effective) flower and defoliation, which cannot be predicted from degree day sums, are an estimate based on experience elsewhere in the tropics and can vary by ± 2 weeks depending on crop stress (water, N, climate) and boll retention early in flowering.

Calculation of half monthly rainfall and solar radiation variably was made using the SAS statistical system version 9.4, climate data was from the silo data base.

A.2 Settings for APSIM-OZCOT simulations

<u>Common Settings</u>

Variety:	SC71B3F
Plants per m of row:	7
Row width:	1m
Planting rule:	After a total of 30mm rain within 3 days and at least 20 mm of soil water.
Climate Data:	Daily data from Silo data base 1957 to 2019.

<u>Specific Settings</u>

Parameter	Planting window	Nitrogen	Soil water	Soil surface
Sowing date	Variable	1 to 15 Jan	1 to 15 Jan	1 to 15 Jan
Nitrogen Fertiliser	100 kg N/ha split 50:50 sow & 14/2	Variable	150 kg N/ha split 50:50 sow & 14/2	Variable
Available soil water	Tippera 122 mm Blain 138 mm	As for sowing date	Variable	As for sowing date
Soil NO3 / NH4 kg/ha at planting	Tippera 16.3 / 5.5 Bain 14.8 / 0.9	As for sowing date	As for sowing date	As for sowing date
Organic carbon %	Tippera 0.5 Bain 0.7	As for sowing date	As for sowing date	As for sowing date
Mulch cover	2 t/ha legume C: N =40 (stylo)	As for sowing date	As for sowing date	0.5 t/ha sorghum 2 t/ha sorghum C: N = 80 2t/ha legume

Annual resetting of parameters:

The aim of all the scenarios simulated was to commence each season with the same soil water, chemical analysis and mulch cover.

A.3 Background: OZCOT-APSIM Model

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 validated for spring sown crops at temperate latitudes and irrigated dry season crops in the tropics. 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, permitting simulation of production system scenarios involving a range of crops using a common soil module (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.

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