Tropical North Queensland Farmers' (Gilbert & Einasleigh Catchment)

Produced by: De-risking broad acre cropping options in Northern Australia

Daniel Rodriguez, Joseph Eyre, Peter de Voil, Ian Broad, Lipy Adhikari and Bhagirath Chauhan



Photo: Sorghum nutrition trial grown at Prestwood Station

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- *We acknowledge and thank the participating farmers and private businesses that have contributed their time, land, and in-kind contributions to this project. Contributing third parties included, Strathmore Station, Prestwood Station, Curra, St Ronans, Radicle Seeds Australia, Elders, Northern Gulf RMG, and AgForce.*
- *This report summarises experimental and modelling results from two years of on farm trials across northern Australia*
- *Even though the promising results from the tested experimental hybrids, commercial reasons dictated that only two of the tested hybrids would be released by the participating companies. Two of the Radicle Seeds Australia hybrids initially tested as experimental by this project have now been released to the market under commercial names of: Anvil and Candela.*
- *Anvil is a mid quick hybrid, having a higher tillering potential than other hybrids on the market. Anvil is capable of high yields due to its tightly packed semi-compact panicle but with only good stress tolerance compared to alternative materials being a good option for irrigated or high yielding environments.*
- *Candela is Australia's first commercial 'waxy' high digestibility sorghum hybrid. The waxy appearance of the endosperm is due to high amylopectin starch content. Waxy sorghums have properties which provide for higher conversion in ruminants and offer benefits in brewing and distillation processes. Candela will be of particular interest to farmers with interest in feed lotting as its energy conversion is comparable to that of white grains (barley or wheat). Candela can also be expected to be preferred by producers of feed for monogastrics (poultry) given its higher digestibility.*
- *Since the start of the project St Ronans Station was added as another case study farm. St Ronans offers local farmers an excellent example of how a cropping enterprise can be managed in rangeland country. Even though its relative success, much needs to be done to diversify and de-risk St Ronans primarily dryland cropping activities, while transitioning to irrigation with bore water resources.*
- *The PhD student Lipy Adhikari is developing her work as part of the team (see contract specifications). We acknowledge and thank CRC NA for the top up to Lipy's stipend and additional operating support. Even though the student milestones will be reported separately this has been a team effort and it is important to acknowledge that (i) a review article was submitted for publication on options to diversify northern Queensland agriculture (attached to this report), (ii) multiple interviews and discussions with local farmers were conducted and a sustainable diversification framework for Northern Queensland was developed, (iii) APSIM was run supported by Peter de Voil (team member) were presented to farmers, (iv) a farmers survey was conducted and responses (n=31) are being analysed with the objective of producing a comprehensive farm typology analysis of existing farm systems, farm enterprises, practices, performance indicators, risk preference, and opportunities to de-risk and diversify production systems, (v) alternative cropping systems were co-designed with StRonans and run with APSIM, summery of these results are presented here.*

Take home messages and recommendations

- Sowing sorghum in hot soils (>36°C) can impair crop establishment and produce uneven stands. *The use of new seed stored in cool temperatures and tested for high germination will be particularly important when sowing crops into the hot soils of northern Queensland.*

- Soil spatial variability remains a significant challenge in the analysis of on-farm replicated experimental data. We used plot drone imagery (NDVI) and electromagnetic surveys as a co-variate in statistical analyses to overcome soil spatial variability. During the second season, we also used electromagnetic surveys to map the spatial variability of the experimental plots. Another important measure for research in northern Queensland is to increase the number of replications to at least four, so that the power of the statistical tests is increased. *It is recommended that future research addresses the issue of spatial variability, typical of soils recently incorporated into cropping, in the experimental design of on farm trials.*

- Adopting practices likely to increase rainfall infiltration offer the greatest opportunity to de-risk cropping across northern Australia and improve environment outcomes. Maintaining ground cover to protect the soil surface structure and subsequently promoting root activity are the main pathways to increase rainfall infiltration while reducing run off and soil erosion. *This calls to rethink crop-livestock integration activities in the north and to demonstrate the short- and long-term benefits of managing ground cover on these fragile environments.*

- We can expect different pathways for intensification and diversification across the different types of farms and farmers in northern Queensland. This is, best fit diversification and intensification options, practices and business models will be influenced by several factors, e.g., farmers' availability of land, labour, skills, water, and capital, as well as by farmers' previous experience, preference and level of risk aversion and dedication to farming – compared to a more lifestyle preference. For example, mixed cropping – grazing farms that presently manage the grazing and cropping activities separately, invest in irrigation infrastructure, and employ highly skilled staff, will have very different pathways to intensify and diversify, compared to those that extensively graze crop stubbles for long periods of time, or haven't had previous experience in cropping. Irrespective of those factors, there is need for business models to be profitable, manage economic and financial risks, be sustainable, regenerate the land, and be resilient to climate or market shocks. Understanding the different types of farms and human resources across the region can help design business models that better deliver across economic, social, human, environmental, resilience, and regional development goals. *An analysis of typologies across the region is being conducted by PhD student Lipy Adhikari. The results of the analysis will help inform opportunities to de-risk the diversification of farming systems in Northern Queensland.*

- Comparing the results from both Kilcummin and Georgetown three commercial (A66, MR Buster and MR Bazley) and three experimental lines (Rex 007, 100393 and PioExp09) were in the top third yielding rank at both sites. This shows good adaptation to the northern conditions in both current and materials that are at different stages of commercialisation. *The results from the two years of hybrid testing across northern Queensland were recently used by Radicle Seeds Australia to release two new hybrids. The new sorghum hybrids are Anvil and Candela.*

- New experimental red, white and high digestibility grain sorghum hybrids produced grain yields that were similar or higher than the yield of well-known commercial check hybrids. The experimental high digestibility sorghums produced approximately 30% digestible higher energy (MJ/ha) than the commercial hybrids. This indicates potential for the identification of hybrids of higher market value and adaptability to Northern Queensland. *Additional information on the economic value, markets and value chains for these new hybrids is needed.*

- Sorghum yields have not significantly responded to increased N application in both low and median rainfall seasons. This can be a typical result in on-farm trials, low rainfall and hot environments. The use of green manures, improved ground cover, the introduction of forage legumes such as Desmanthus, as a sole crop or in association with pastures and even in intercrops with sorghum should be explored further. An important issue is to achieve good establishments of the green manures, forages, and intercrops. *Research is needed to further explore opportunities to more holistically improve the soil fertility (physical, chemical and biological), rather than solely rely on the use of chemical fertilisers.*

- Fall army worm (FAW) remains a significant problem, both to grain and forage crops, especially maize and sorghum north of Emerald. We noticed a trend to use pesticides outside recommended labels, which is a significant risk for the development of resistances. There is also farmers' interest in the combination of chemical and biological controls. *There is need to develop integrated weed and pest control measures and low chemical use farming systems, particularly given the risk of rapidly developing insecticide and herbicide resistances due to mal use of chemicals and the fast cycling of pests and weeds in hot and humid environments.*

- Desmanthus (a perennial leguminous shrub) can persist longer into the dry season than any other crop or weed offering opportunity to increase ground cover during the dry season. Improved Desmanthus establishment rate in sandy loam soils were achieved by broadcasting seed on tilled soil and then rolling. However, opportunities for effective weed control during Desmanthus establishment are limited by slow seedling growth relative to weed vigour and on-set of water stress. *Establishment methods integrating rotations with cash crops, direct drilling, cultural and chemical weed controls require investigation. There are also many varieties showing contrasting adaptation to different environments. There are opportunities to improve the establishment and early vigour of desmanthus stands from identifying better matches between genotypes and practices to site and seasonal conditions.*

- Farmer managed strip trials continue to be a valuable complement to the small plot trials. Strip trials demonstrated similar yields to the small plot trials and highlight the value of small non-significant yield gains between treatments. *Supporting farmers run their own experimentation can be an effective use of limited resources in remote areas, and an opportunity to generate discussion and learning "by doing".*

- A sorghum agronomy guide for Tropical North Queensland farmers (Gilbert & Einasleigh Catchment) was produced, presented, and distributed to farmers. The guide adds to the existing information on the GRDC website. Updates focused on regional achievable yields under dryland and irrigated conditions, the influence of cultivar selection (early, medium or late), the time of sowing, plant population, nitrogen fertilisation, and water requirements if the crop were to be irrigated. The document also addresses specific issues for weed control on light sandy loamy soils, and the high pest pressure.

Background

In Northern Australia multiple constraints create complex problems requiring partnerships between farmers, researchers, and agribusinesses to adapt known practices and build skills into profitable and low risk broad acre cropping activities. Given that Northern Australia is relatively new to dryland cropping, the need to identify best crop and management options that bridge gaps between present and achievable yields remains highly relevant. This project is supporting farmers and agribusinesses identify best fit grain cultivars, agronomic practices that maximise rainfall harvesting and increase water use efficiency and provide diversification options to primarily rangeland grazing businesses.

Farmers are likely to benefit from having a better understanding of the best combinations of agronomy and cultivars of cereals to the growing conditions and markets of Northern Australia. Agribusinesses will benefit by increasing the efficiency of crop improvement programs for Northern Australia, a higher demand of agricultural inputs, and by an improved availability of locally developed technical information. Northern Australia will benefit from an expected increase in economic activity, employment opportunities and diversification of livelihoods that protect existing businesses from climate, policy and market shocks and changes.

Stakeholder learning objectives

Stakeholders' learning objectives were identified from meetings with farmers and agribusinesses and remain valid during the second year of trials.

Key priorities to de-risk broad acre cropping across Northern Australia include:

1. Identify adapted summer grain varieties for the north. Common to all farmers and private sector partners was the need to understand how to maximise yield and yield stability by identifying the most suitable varieties given the extended planting window of Northern Queensland. For example, depending on the start of the monsoon, in the Gulf, the planting window is likely to span between early January and late March.
2. The management of crop nutrition in cereals. Common to most farmers was also the need to identify optimum sources and rates of nutrients to fit soil type and condition.
3. Improvement topsoil infiltration. Improvement to the topsoil structure is required to increase rainfall harvesting and increase soil water content. This is expected to reduce the dependence of crop on highly variable rainfall events particularly around critical stages for grain yield determination around flowering.

Summary of seasonal conditions 2019/20 and 2020/21

The 2019/20 season in the Gilbert Catchment could be characterised by its late start (February), its early finish (March), and the occurrence of few though intensive rainfall events. Most of the total 2019/20 season rainfall (Strathmore Station = 588 mm; Prestwood Station = 502 mm) fell in four intensive events beginning in late January (Figure 1). As a contrast, the rainfall for the best 1999/2000 and 2016/17, and worst 2002/03 and 2014/15 growing seasons are also shown in the graph below in dashed lines. The graph shows that the 2019-20 season, or first season of trials was one of the driest on record, and means that the crops were exposed to terminal drought conditions, after the last substantial rainfall event (12/3/20 at about 12 expanded leaves in the sorghum). Under these conditions the capacity of the crops to access soil moisture from deeper soil layers, during and after flowering, would determine crop success or failure. The availability of soil moisture in deeper soil layers will depend on rainfall infiltration, the capacity of the root system to access deeper soil layers, and the lack of subsoil constraints such as compacted layers, toxicity, salinity or sodicity. The 2019/20 season demonstrated the value of soils having high and poor infiltration capacity, and therefore high and low rainfall harvesting capacity. At Strathmore Station, the site was characterised by a sandy loamy soil having extremely poor superficial structure and low infiltration, due to the presence of a compacted soil layer and the sealing and crusting of the soil surface. Though this was not a generalised problem, but just a particular problem at the selected plot. This combination of poor rainfall infiltration and seasonal conditions were the main causes of the trial and most farmers' fields producing no yield. In contrast, at Prestwood Station, the site was characterised by coarser

sandy topsoil having high infiltration capacity but still high rainfall runoff due to topography and surface physical characteristics. Sorghum yields at Prestwood Station during this season were low, though didn't cause a crop failure. It is important to note as well that at both Strathmore Station and Prestwood Station, the soils were new to cropping activities. At Kilcummin (Burdekin Catchment) and Capella, seasonal and site conditions were much more favourable due to two main reasons (Figure 2). First the soils have been under cropping for over 20 years, the dominant soils are brown vertosols of high rainfall capture and high-water holding capacity, so that despite a low in crop rainfall (102 mm), trial yields were much higher than those in the Gilbert.

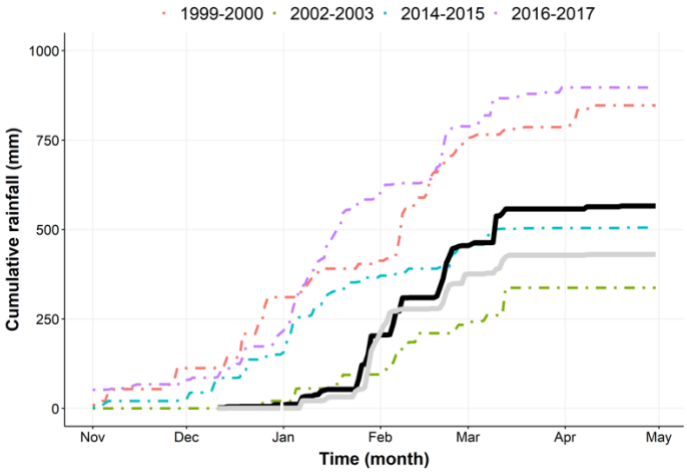


Figure 1. Cumulative rainfall at Strathmore Station (solid black line) and Prestwood Station (solid grey line) Georgetown for the research trial in 2019/20 season, versus seasons with best (1999-2000, 2016-2017) and worst (2002-2003, 2014-15) growing season rainfall. At Strathmore Station, the crop was sown on the 3rd February 2020.

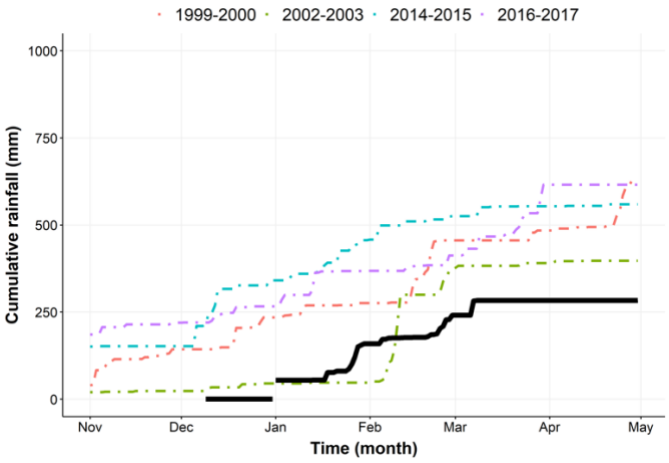


Figure 2. Cumulative rainfall at (solid black line) Kilcummin and Capella for the research trial sown in the 2020 season, versus the 2014-2015 and 2016-2017, and 1999-2000 and 2002-2003 growing season rainfall. At Kilcummin, the sorghum crop was sown on the 14th February 2020. During the 2019-20 season four out of the five planted researcher managed trials were harvested. Harvested sites included variety trials at Capella and Kilcummin, and nutrition trials at Georgetown and Kilcummin. The trial site at Strathmore Station was decommissioned due to drought and fall armyworm (FAW) damage.

In contrast, the 2020/21 season in the Gilbert Catchment was a La Niña season, characterised as wetter than average. The season included flooding during December and in late April, with a dry period in during March. Georgetown's seasonal rainfall was in the top 80% of the years (wet). The season at the Kilcummin (Curra) site, in the upper Burdekin, was drier than average (Figure 3).

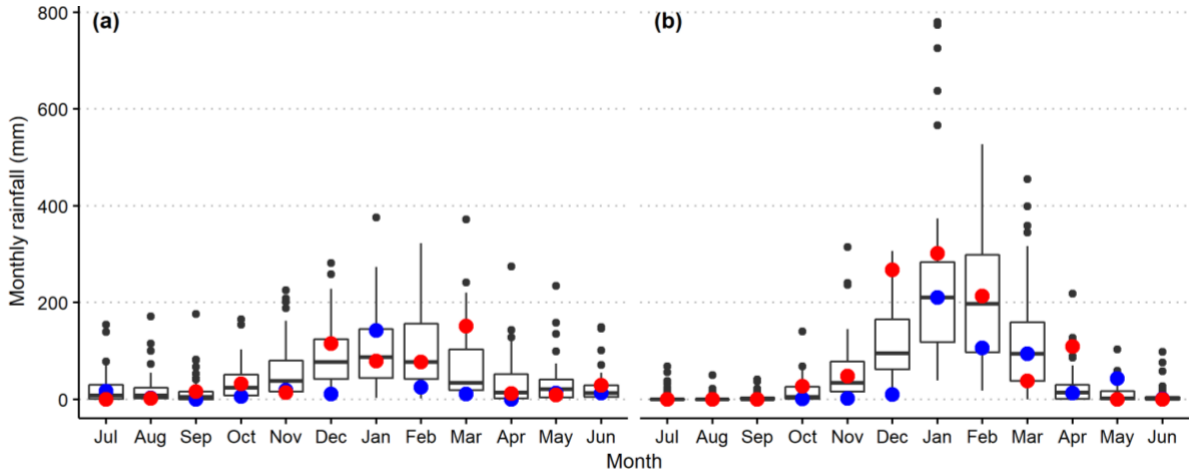


Figure 3. Boxplots of monthly rainfall distribution for the period 1960 to 2021 at the (a) Clermont and (b) Georgetown Bureau of Meteorology weather stations. Large blue circles show monthly rainfall for the 2019-20 season, and red circles for the 2020-21 season. The small black circles indicate extreme monthly rainfall defined as more than two standard deviations different from mean monthly rainfall.

As indicated above, soils will modulate the seasonal condition. Though only in well-structured soils, having ground cover to maximise infiltration and rainfall harvesting, such as in the Burdekin sites in this study. In contrast, in the sandy loamy soils at some of the sites in the Gilbert, the poor natural soil structure of the topsoils, their tendency to seal and crust, the high rainfall intensity, the soil compaction due to cattle trampling meant that the crops were more vulnerable to dry conditions. Climate analyses reveal that dryland crops in the Gilbert Catchment need to withstand dry periods averaging 20 to 30 days long each season (Table 1). Even though, soils in the region can retain approximately 90 to 130 mm of plant available water to buffer these dry spells, soil degradation, soil compaction, and poor ground cover reduces rainfall infiltration and promote run off and erosion processes meaning that only a fraction of the soil water holding capacity is filled by rainfall.

Table 1. Wet season climate analysis for the Gilbert Catchment.

Means followed by standard deviation in parenthesis. Data sourced from Australian Bureau of Meteorology (1960 to 2021)

Climate station	Start date (days)	Duration days	Longest period without rain days	Rainfall (mm) max	min	median	CV
Croydon	07-Dec (20)	100 (29)	26 (33)	1936	137	668	41
Georgetown	03-Dec (25)	103 (32)	28 (35)	2376	128	723	43
Prestwood	08-Dec (20)	96 (30)	20 (22)	2208	112	630	46
Strathmore	04-Dec (24)	101 (28)	30 (38)	1926	95	710	40

Adapted sorghum varieties for northern Queensland

Commercially available Australian sorghum hybrids are primarily developed and tested for dryland cropping environments of Northern New South Wales and Southern Queensland. Large seed

companies do not produce or test materials under dryland conditions across Northern Queensland. This means that there is lack of specifically adapted germplasm for the semi-arid tropics.

In the two seasons of trials 2019 to 2021 identical trials, designed in collaboration with SAGI-Queensland (QDAF), were planted using UQ-QAAFI precision research planter at Kilcummin, Capella and Georgetown. Treatments included 41 commercial and experimental hybrids, with two replications. Plots were at least 20 m^2 (Table 2).

Table 2. Crop cultivars sown in sorghum variety trial at Kilcummin and Georgetown during the 2019-20 and 2020-21 seasons.

Crop	Source	Entry	Entry#
Grain Sorghum	Heritage Seeds	Archer	1
Grain Sorghum	PacSeed	Buster	2
Grain Sorghum	Pioneer Seeds	G33	3
Grain Sorghum	Pioneer Seeds	A66	4
Grain Sorghum	Pioneer Seeds	A75	5
Grain Sorghum	Pioneer Seeds	PioEXP09	6
Grain Sorghum	Radicle Seeds	Agitator	7
Grain Sorghum	Radicle Seeds	Agitator	8
Grain Sorghum	Radicle Seeds	Exp1	9
Grain Sorghum	Radicle Seeds	Exp2	10
Grain Sorghum	Radicle Seeds	Exp3	11
Grain Sorghum	Radicle Seeds	Exp4	12
Grain Sorghum	Radicle Seeds	Exp5	13
Grain Sorghum	Radicle Seeds	Exp6	14
Grain Sorghum	Radicle Seeds	Exp7	15
Grain Sorghum	Radicle Seeds	Exp8	16
Grain Sorghum	Radicle Seeds	Exp9	17
Grain Sorghum	Radicle Seeds	Exp10	18
Grain Sorghum	Radicle Seeds	Exp11	19
Grain Sorghum	Radicle Seeds	Exp12	20
Grain Sorghum	Radicle Seeds	Exp13	21
Grain Sorghum	Radicle Seeds	Exp14	22
Grain Sorghum	Radicle Seeds	Exp15	23
Grain Sorghum	Radicle Seeds	Exp16	24
Grain Sorghum	Radicle Seeds	Exp17	25
Grain Sorghum	Radicle Seeds	Exp18	26
Grain Sorghum	Radicle Seeds	Exp19	27
Grain Sorghum	Radicle Seeds	Exp20	28
Grain Sorghum	Radicle Seeds	Exp21	29
Grain Sorghum	Radicle Seeds	Exp22	30
Grain Sorghum	Radicle Seeds	Exp23	31
Grain Sorghum	Radicle Seeds	Exp24	32
Grain Sorghum	Radicle Seeds	Exp25	33
Grain Sorghum	Radicle Seeds	Exp26	34
Grain Sorghum	Radicle Seeds	Exp27	35
Grain Sorghum	Radicle Seeds	Exp28	36
Grain Sorghum	Radicle Seeds	Exp29	37
Grain Sorghum	Radicle Seeds	Exp30	38

Grain Sorghum	Radicle Seeds	Exp31	39
Grain Sorghum	Radicle Seeds	Exp32	40
Grain Sorghum	Radicle Seeds	Exp33	41

Establishment and canopy cover

In the first season sorghum was sown at twice the locally recommended population density due to the expectation of large establishment loses. However, an 83% establishment rate was achieved for some hybrids, which is better than the establishment rates reported under favourable conditions in southern dryland cropping regions (Figure 4).

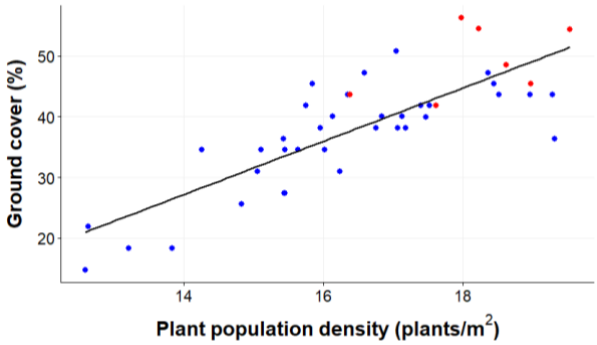




Figure 4. Ground cover obtained with drone imagery at floral initiation at Strathmore Station Georgetown, versus the established population density for commercial checks (red dots), and experimental hybrids (blue dots). Photograph of the Strathmore sorghum variety trial on 21st April showing high rate of establishment in a plot sown with experimental hybrid 13/39.

Grain yields

In the 2019-20 season, at both sites in Kilcummin and Capella, some of the new experimental red, white and high digestibility grain sorghum hybrids produced grain yields similar or higher than the yields from the commercial check hybrids (Figures 5 and 6). Yield differences between hybrids of up to 4t/ha were recorded. Six of the experimental hybrids coincided as the highest yielding hybrids (top yielding tercile) at both sites (this is hybrids 100404, 100481, Rex013, 100412, 100477 and Rex012 (Figures 5 and 6).

At Kilcummin the two highest yielding commercial hybrids were Agitator and Brazen (with just over 4t/ha), from Radical Seeds Australia, these are hybrids adapted to Central Queensland environments. At Capella the highest yielding commercial hybrids were A75 from Pioneer and MR Buster from Pacific Seeds. It is important to note that at these sites, soil characterisation and electromagnetic survey across the site identified irregular 10 to 50m wide patches of sub soil sodic salinity at approximately 1.5 to 3 m depth. These are subsoil constraints known to limit crop rooting depth, and the capacity of crops to uptake water (high osmoticum). The large spatial variability at this site explained the high variability observed across the trial. Post-harvest soil moisture measurements at Curra, confirm that plots with visibly supressed yield had 30mm less soil moisture extraction below 120cm depth.

During the second year of trials, we increased the number of replications, and the trial design was also informed by an electromagnetic survey as a covariate in the statistical analysis.

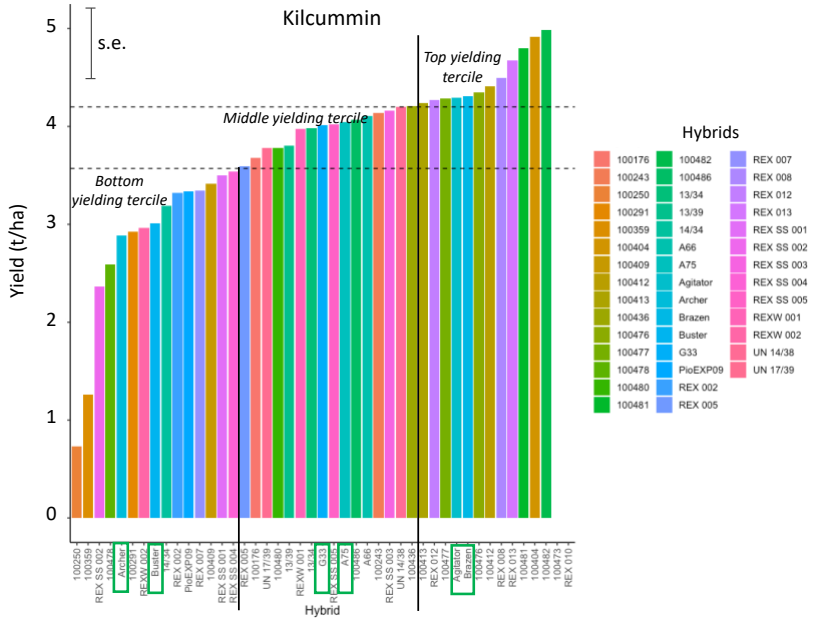


Figure 5. Mean yields, dry basis, for the different hybrids tested at "Curra" Kilcummin, Qld during the 2019/20 season.

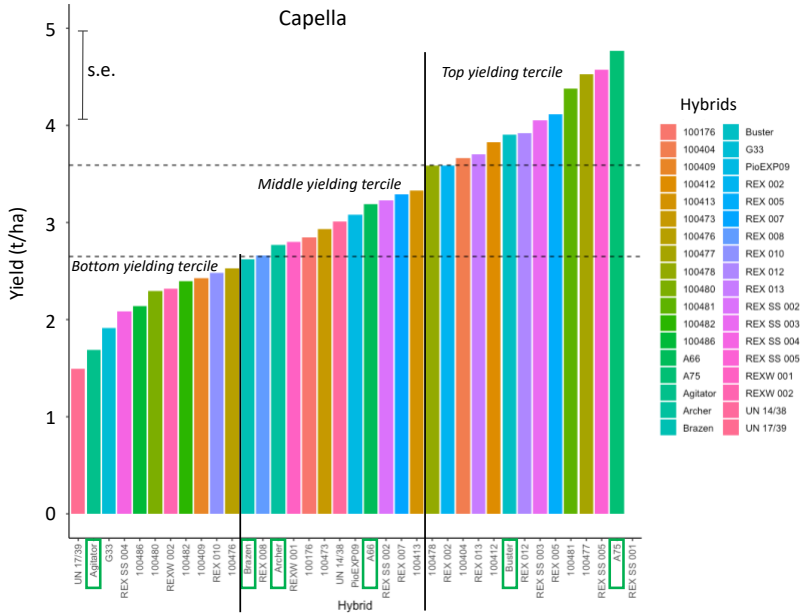


Figure 6. Mean yields dry basis, for the different hybrids tested at "Manar" Capella, Qld during the 2019/20 season.

During the second season of trials results were like those from the first season (Figures 7 and 8). At Kilcummin, some new experimental red (e.g., SG12643) and white (e.g., 100390) grain sorghum hybrids produced grain yields similar or high than the yields from the commercial check hybrids (e.g., G33, Cracka). As expected, the experimental high digestibility hybrids (REX SS 001 to REX SS 005) yielded significantly lower than the commercial checks (A66, A75, Sentinel, Buster and G33). Though when the higher digestibility is taken into consideration, value for feed production can be expected to be like that of commercial hybrids. Radicle Seeds Australia is presently working to increase yield in the high digestibility hybrids.

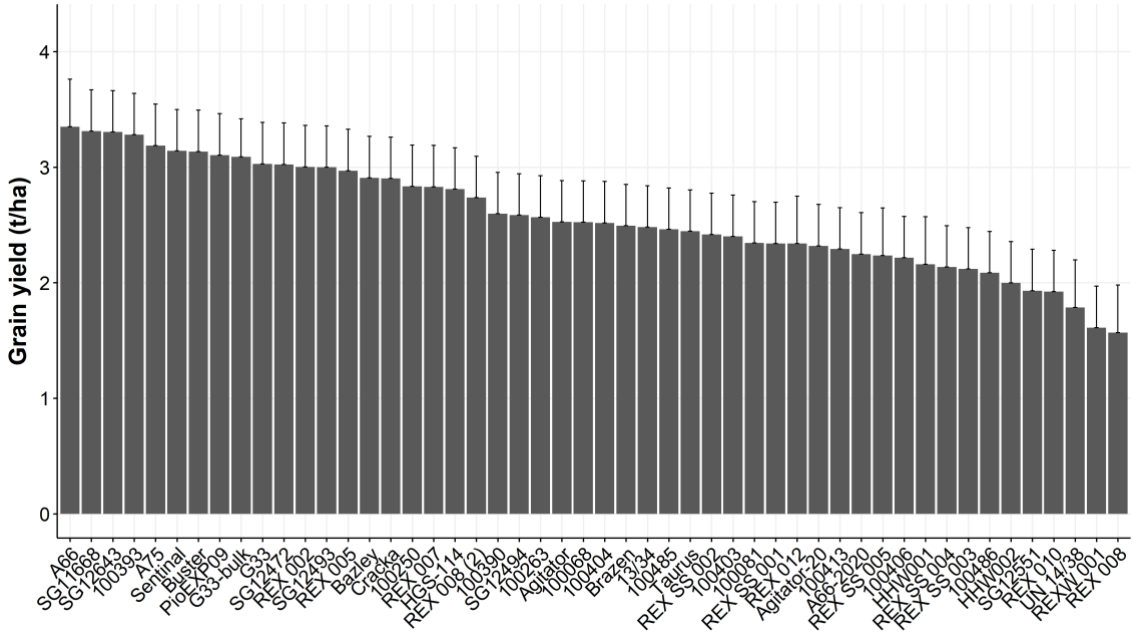


Figure 7. Mean sorghum grain yields (dry basis) for commercial hybrids, experimental red, experimental white and high digestibility hybrids at "Curra" Kilcummin during the second season of trials (2020-2021). Bars indicate standard error. Average L.S.D.(P=0.05) = 0.417 t/ha

At Georgetown (Strathmore Station), the highest yielding hybrids were Pioneer A66, Pacific Seeds MR Taurus and Radicle Seeds Agitator. Some of the new experimental red and white hybrids were also yielding in the top 30% of the hybrids (e.g. Rex007 and 100390) close to well-known commercial hybrids such as MR Buster.

Comparing the results from both Kilcummin and Georgetown three commercial (A66, MR Buster and MR Bazley) and three experimental lines (Rex 007, 100393 and PioExp09) were in the top third yielding rank at both sites.

The results from the two years of hybrid testing across northern Queensland were recently used by Radicle Seeds Australia to release two new hybrids. The new sorghum hybrids are Anvil and Candela. Anvil is a more flexible hybrid with capacity to yield across a wider range of environments. Candela is the first 'waxy' high digestibility hybrid to be released in Australia. This hybrid has high amylopectin starch that provides a higher conversion efficiency in ruminants and can be used in the brewing and spirit distillation industries.

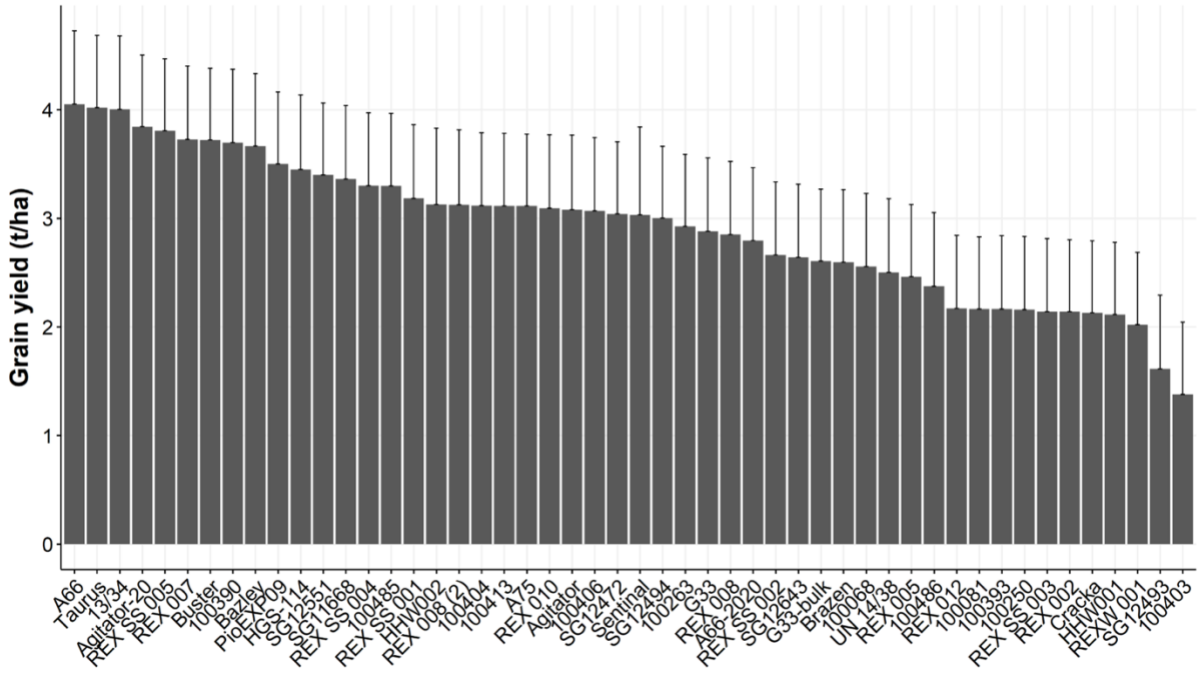


Figure 8. Mean sorghum grain yields for commercial hybrids, experimental red, experimental white and high digestibility hybrids at "Strathmore Station" Georgetown in 2020-2021. Bars indicate standard error. Average L.S.D.(P=0.05) = 0.8 t/ha

The management of crop nutrition in northern Queensland

Presently, there is limited information on the management of crop nutrition for soils of the Gilbert Catchment, and highly contrasting crop fertilisation management approaches are presently used by different farmers across the Northern Central Highlands region.

Results from the soil tests of the Gilbert region identified that most soils had very low levels of carbon and nutrients. However, frequent, and long dry spells, combined with hot weather conditions, poor soil water holding capacity, and limited rainfall infiltration due to poor soil surface structure are likely to limit yield responses to nutrients when conventional mineral fertilisers are applied at sowing. In these environments high nitrogen use efficiencies can be expected to be achieved when soil nitrogen supply and crop demand are better synchronised. This is high levels of nitrogen early in the season will induce the growth of leaf area during early vegetative stages. Early leaf area growth will induce water use early in the season. We know that in environments dominated by terminal water stresses the transfer of water use from vegetative to reproductive and grain filling stages can increase the likelihood of crops being harvested and increase grain quality (reduced screenings). Therefore, the objective of these trials was to compare the use of conventional mineral fertilisers, as well slow release biological fertilisers, that have shown capacity to re-activate soil biology in highly degraded soils i.e. a product from Australia Soil Planners (ASPLF, http://soilplanner.com.au/) at both Georgetown and Kilcummin.

Replicated trials were planted using one hybrid (G33) and 6 fertiliser treatments including current practice (farmers practice differed between sites), four nitrogen rates (0, 8, 54, 100 and 192 kg/ha), two N sources and were repeated over two seasons (Table 3). Trials were planted at Prestwood Station (Georgetown) and Curra (Kilcummin). The nitrogen sources included a liquid nitrogen

product from Incitec Pivot (Easy N) plus a basal level of a starter fertiliser (Start UP ZN), and a biological active liquid fertiliser produced by Australia Soil Planners (ASPLF) as an alternative "biological" fertiliser. The level of N in the application of starter fertiliser was equivalent to that in current practice ~ 8 kg N/ha. Economic results are not included because the cost of using ASPLF versus the use of common practice using conventional fertilisers (~ 80kg N/ha) are comparable. This means that the simple relative yield comparison between treatments should be equivalent to a gross margin comparison.

Table 3. List of treatments for the crop nutrition farmer driven trial at Curra and Prestwood Station

Treatment	Easy N (l/ha)	Start UP ZN (l/ha)	ASPLF (l/ha)
0 kg N/ha Control	0	0	0
8 kg N/ha (starter only)	0	86	0
54 kg N/ha + starter	100	86	0
100 kg N/ha + starter	200	86	0
192 kg N/ha + starter	400	86	0
Biological (ASPLF)	0	0	80

The results from the first season of trials at Prestwood Station need to be considered with caution, given the extremely dry conditions experienced by the crops in the Gilbert. Having said that the nutrient responses from Prestwood Station in Georgetown and Curra in Kilcummin, showed clear similarities.

At both sites, the lowest biomass production and yield were obtained with the control with no application of additional nutrients, and with the treatment that only used starter fertiliser. This is, only 8kg N/ha, and small additions of phosphorus and zinc. The biological liquid fertiliser performed similar or slightly better than the control with no addition of nutrients. Nitrogen inputs between 54 and 100 kg N /ha produced the highest yields, and the highest level of fertilisation reduced yields again. Water stress induced by relatively short wet season most likely masked any responses to the nitrogen fertilisation.

In Georgetown, crop biomass production exceeded expectations for such as harsh rainfall season. Grain sorghum crop residues defined as total above ground biomass without grain, averaged 6 t/ha at Prestwood Station. Grain yields of 4.5 t/ha could be expected assuming a conservative harvest index estimate of 0.4 and adjusted to 13.5% moisture content. Actual grain yields at Prestwood Station are not shown due to severe bird damage. Bird damage was severe even though a bird scarer gun and automatic laser bird deterrent were installed and fully functional from anthesis to maturity. Bird pressure at other sites was less as the damage was diluted across a large area of planted crop. At Prestwood Station, only a small area of sorghum was planted.

At Kilcummin grain yields increased by 16.5% when nitrogen inputs were increased from 0 to 54 kg/ha, then plateau with 100 kg/ha, and declined with 192 kg/ha N. The decline in yields was probably driven by excessive early growth and water use during vegetative stages.

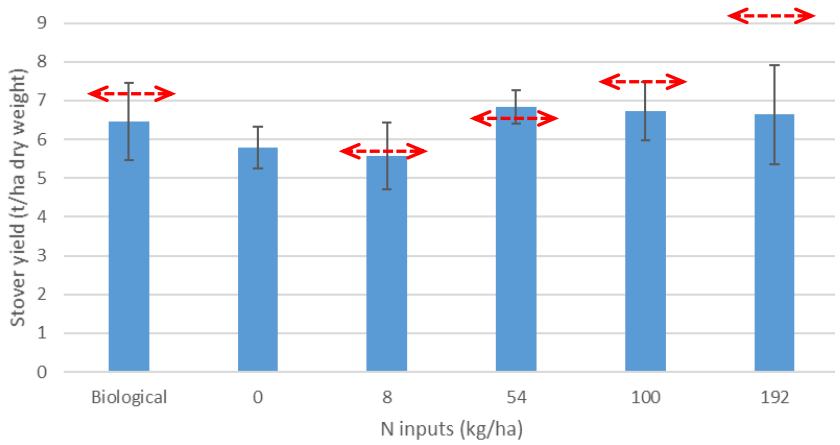


Figure 9. Stover yields from sorghum's nutrition trial at "Prestwood Station", Georgetown. See the table for treatment descriptions. The red arrows indicate the minimum treatment yield required for the practice to be profitable, according to N rate applied, and the prices of grain and N fertiliser as per June 2022. N responses were estimated assuming a harvest index = 0.4.

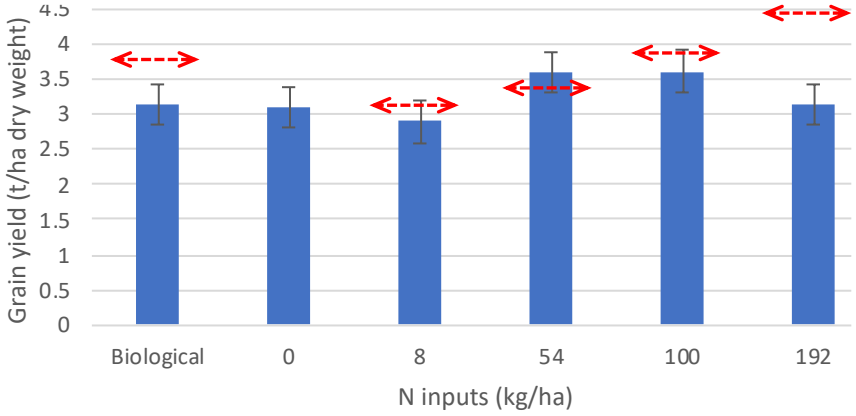


Figure 10. Grain yields from sorghum's nutrition trial at "Curra", Kilcummin. See the table for treatment descriptions. The red arrows indicate the minimum treatment yield required for the practice to be profitable, according to N rate applied, and the prices of grain and N fertiliser as per June 2022.

During the second season of trials three replicated trials were planted using one hybrid (G33) including current practice, 4 nitrogen rates (0, 10, 40, 90 and 170 kg/ha) and two N sources. The three identical trials were planted at "Prestwood", "Strathmore" (Georgetown) and "Curra" (Kilcummin). Treatments included a control with no fertilisation, three levels of nitrogen (N) fertilisation using a liquid nitrogen product from Incitec Pivot (Easy N) plus a basal level of a starter fertiliser (Start UP ZN; Rutec), and a biological active liquid fertiliser produced by Australia Soil Planners (ASPLF) as an alternative fertiliser (Table 4).

Given June 2022 fertiliser and grain prices the minimum crop yield required to produce an economic response was calculated and indicated as a red arrow in the figures above (Figures 9 and 10). The calculation assumes urea prices of AU1100/t and sorghum grain prices of AU320/t, this is, a minimum yield response from the addition of fertilisers required to pay the practice of about 7.5 kg grain/kg of N applied. The trial results show that for both trials the most economic rate of N fertilisation was 54kg N/ha. In Figure 9 results are presented in terms of stover yield as yields were estimated using a harvest index =0.4, as the crop was severely damaged by birds.

Table 4 List of treatments for the crop nutrition farmer driven trial at "Curra", "Strathmore" and "Prestwood" stations

Treatment	ID	Easy N (l/ha)	Start UP ZN (l/ha)	ASPLF (l/ha)
Control	0N-0S-0B	0	0	0
48 kg N/ha (starter only)	0N-1S-0B	0	86	0
54 kg N/ha + starter	1N-1S-0B	100	86	0
100 kg N/ha + starter	2N-1S-0B	200	86	0
192 kg N/ha + starter	3N-1S-0B	400	86	0
Biological (ASPLF)	0N-0S-1B	0	0	80

The APSIM model was tested for the region against trial and farmers' data and used to simulate the expected returns in kg grain per kg of applied nitrogen, for fertilisation levels varying between 20 and 300 kg N/ha. We used a sandy-loamy soil parameterised at Tonks Camp (Georgetown) i.e., 150mm plant available water capacity (PAWC). The model was run over 50 years of climatology (Georgetown). At sowing the soil was dry (20% PAWC) and the crop was sown on a rainfall event of at least 30mm accumulated over 3 days. At sowing a ground cover of 1000 kg/ha was assumed. The fertilisation scenario included a control with 10kg N/ha, as well as 10kg N/ha increments to 100kg N/ha, 150, 200, 250 and 300 kg N/ha. Soil infiltration was restricted to account for the high level of soil degradation observed in the region (i.e., runoff curve number=80). Results are presented below (Figure 11) in boxplots for the simulated yield in function of the level of fertilisation, and in terms of the simulated response to the addition of fertilisers.

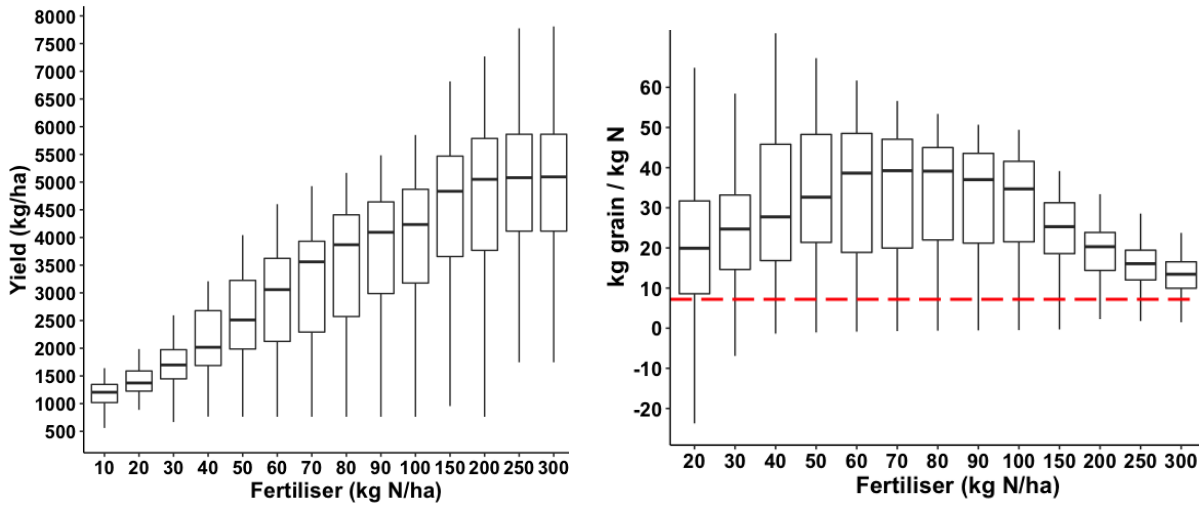


Figure 11. Grain yields and the response to the addition of fertilisers versus the level of N fertilisation on a sandy loamy soil typical of the Gilbert catchment (Tonks Camp soil). The red dashed line indicates the minimum response required to cover the cost of fertilisers based on June 2022 grain and fertiliser prices.

This figure shows that the profitability of the practice is highest and risks lowest for N application rates of between 40 and 60 kg N/ha. The maximum chances of negative returns (about 25%), downside risk, can be expected at very low levels of fertilisation, 20kg N/ha. Though it is important to note that the variability in the response to nitrogen fertilisers is large, as north Queensland's climate is highly variable. Factors that will reduce this variability include increasing rainfall infiltration through stubble retention,

sowing into a full soil profile, rotating cereals and legumes, primarily deep-rooted legumes such as pigeon peas and sun hemp. Cotton is also a deep rooted and high value crop highly suitable for the region to be grown rainfed or under irrigation.

Fall armyworm (FAW) on maize

FAW remains a significant threat to maize production across the region. It should be noted that some of the FAW free maize crops observed across the region have been managed using off label applications of insecticides. Labels should be used in the use of insecticides as off label application carry a significant risk contributing to develop insecticide resistance. Maize is an important crop, particularly in systems that rotate with cotton. If maize is to succeed in the north alternative approaches to the control of FAW need to be urgently developed.

Our trials were treated with two fortnight applications of Spinetoram 120g/L (or 250g/kg) at a cost of 600 $/L.. More information can be found at GRDC's https://grdc.com.au/resources-and-publications/resources/fall-armyworm The latest trap counts in Queensland are recorded and available at https://thebeatsheet.com.au/

Fall armyworm (FAW) on sorghum

As per the 2021/22 summer, fall armyworm was detected in sorghum at all our trials, from northern Queensland to Northern New South Wales. During the first season sorghum host plant resistance was assessed following a leaf damage scoring (Davis Scoring system). Damage was localised in sections within plots and correlated with ground cover rather than genotype (Figure 12). FAW moths deposited eggs and once the eggs hatched the 1st instars spread on to nearby plants causing local spot infections. Controlling FAW infections in maize is recommended early when the larvae is in their 1st to 3rd instars. Sorghum has a much larger capacity to compensate loss of foliage but we recommend regular crop inspections. There is some initial information at https://grdc.com.au/resources-and-publications/resources/fall-armyworm and QDAF's web site https://thebeatsheet.com.au/

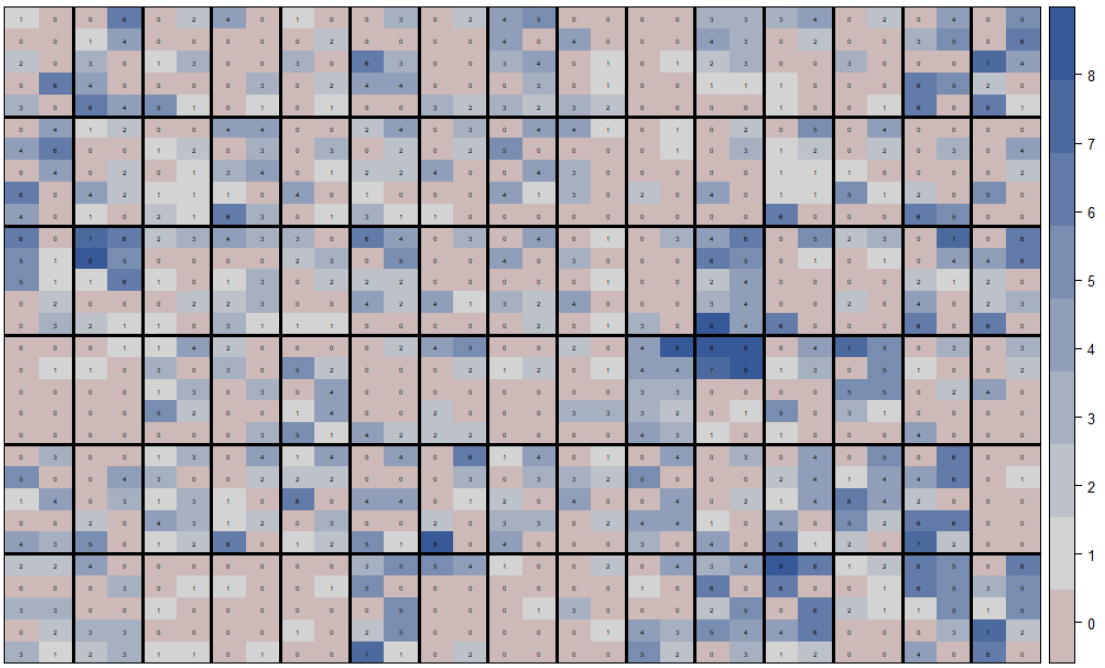


Figure 12. Map of sorghum genotype adaptation trial at "Strathmore Station" showing the degree of FAW damage to 10 plants per plot. In the graph, the black grid lines identify plots, and the blue to pink squares identify plants. The number inside each box indicate the degree of damage observed, this is, 0 = no damage to 9=large holes on most leaves.

Farming system trials

- Forage sorghum, Cowpea, pigeon pea, *Desmanthus* and sunhemp showed the greatest potential for inclusion in a low risk sorghum-maize cropping system.
- A farmer managed strip trial consisting of an intercrop of cowpea and sorghum rapidly covered the soil and out competed weeds.
- *Desmanthus* (a perennial leguminous shrub) persisted longer into the dry season than any other crop with substantial tap roots such as pigeonpea and sunhemp.
- Improved *Desmanthus* establishment rate is required for industry uptake of this forage legume especially in sandy loam soils. Best establishment was obtained with a very shallow sowing, at 1-2 cm. This could be obtained by broadcasting the seed and using a rake or similar implement.
- All forage sorghum hybrids showed rapid canopy coverage and ability to out compete weeds even in sandy soils. Most forage sorghums though, failed to persist into the dry seasons. This was an interesting observation as grain sorghum did ratoon several times at the Prestwood site, and was grazed during the dry season when no other source of fodder was available.
- Farmer managed strip trials were a valuable complement to the small plot trials. Strip trials demonstrated the value of pre-plant soil moisture reserves in the Gilbert catchment. Grain sorghum strip trials were similar yielding to the small plot trial averaged across all treatments.

De-risking farm diversification of Northern Queensland's farming systems. *By Lipy Adhikari (PhD candidate)*

Across Northern Queensland, farmers' livelihoods are largely dominated by extensive dryland beef-cattle farming activities (Webster et al 2013, CRCNA 2020). These farming systems are extremely vulnerable due to high levels of climate variability, limited and volatile market options and unsustainable practices. Ongoing changes in rainfall and temperature associated to climate change, are expected to further affect pasture productivity, and increase variability in livestock production and farmers income (Oba 2001, Coppock 2011, Allred et al 2014, Godde et al 2019). Therefore, identifying, and quantifying farmers' options to diversify their farming systems are needed for increased resilience and long-term sustainability (Olsauskas et al 2018, ClimateWorks Australia 2020).

Farm diversification offers opportunities for the cattle stations to diversify sources of income, manage market volatility and build business resilience to climate shocks and trends (Olsauskas 2018, Medhrust et al 2007). According to Kandulu et al (2012), enterprise mix diversification is the most widely used strategy for mitigating diverse set of risks associated with agriculture enterprises.

Diversification is however highly context specific, and its success largely depends on the opportunities and challenges (Turnour et al 2021). Some of the likely constraints to diversification are associated to production, financial, environmental, market, and human (available skills and labour) risks (White et al 2002, Culas 2006, Medhrust et al 2007). Here we conducted an ex-ante, fore-sighting analysis of potential options to diversify an existing 44,000 ha mixed cropping and grazing farm business from the upper Gilbert catchment. This fore-sighting exercise is expected to contribute to the discussion on de-risking the sustainable diversification of agriculture in Northern Australia with farmers, agri-businesses, and policy.

Material and methods

A case-study farm from the upper Gilbert catchment area (Figure 13) was identified with the help of the Gulf Savannah NRM. The selected property was originally a cattle-station. That in 2019, diversified into a 2000ha dryland cotton-maize production system (referred to as "Present" in the text) (Figure 14). The main objective of the farmer is to introduce an irrigated, double cropping system, with cotton as a centre crop, increase ground cover, rainfall infiltration and carbon sequestration, as well as profitability and profit stability (risk exposure) of farm business. As per 2022, centre pivot irrigators have been installed to irrigate 340 ha of the cropping area using bore water.

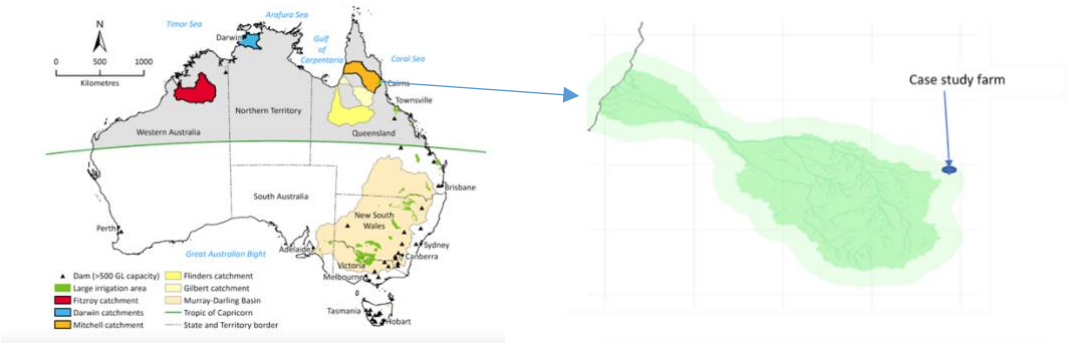


Figure 13. Map of Australia (source: Watson et al 2018) and the greater Gilbert catchment

Table 5. Name and description of the co-designed and tested cropping system scenarios.

Scenario	Year 1	Year 2	Year 3	Year 4
Current (dryland)	maize	cotton	maize	cotton
mbc (irrigated)	maize-barley	cotton	maize-barley	cotton
msc (irrigated)	maize-soybean	cotton	maize-soybean	cotton
mmc (irrigated)	maize-mungbean	cotton	maize-mungbean	cotton
winter mc (irrigated)	winter maize	cotton	winter maize	cotton
mc (irrigated)	maize	cotton	maize	cotton

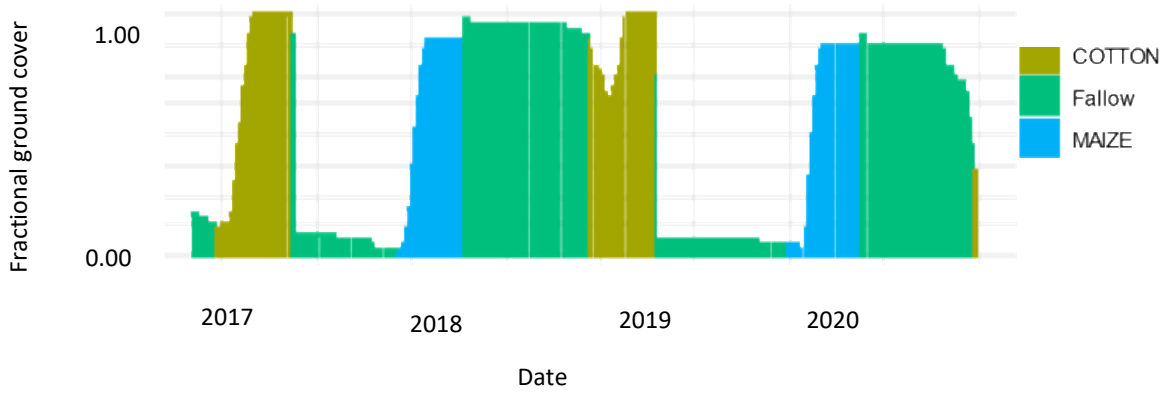


Figure 14. Time series of simulated fractional ground cover for the present cropping system: Cotton – Fallow - Maize

Researchers and the case-study farmers were engaged in an *iterative process* to co-design alternative crop production systems that resulted in a range of feasible scenarios (Table 5). A crop simulation model i.e., APSIM, was used to quantify benefits and trade-offs from the alternative scenarios, in terms of gross margins, downside risk i.e., likelihood of a gross margin lower than 1000 $/ha, soil cover and water use efficiency. Economic calculations were performed including resources from AgMargins (https://agmargins.net.au/Reports/Index#) and local knowledge.

Preliminary results

This section presents preliminary results being discussed with the participating case-study farm.
The present system includes dryland, cotton-maize production system, with cotton as a centre crop. Both cotton and maize crops are sown between the second and the third week of December. Farmers use short and compact crop varieties to make the most out of the rainfall events during this period and to manage weeds. The crops are harvested in June-July, thus, one of the main limitations of this single cropping system is long fallow periods that exists between the crops (Figure 14). With pivot irrigators in place, the farmers are exploring opportunities to grow winter crops and summer legumes and implement a double cropping system to increase ground cover as well as the overall gross margin of the farm. The “mc” scenario involves growing a short maize variety under irrigation, sown during the same sowing window as the dryland scenario. Given the high rainfall environment at the site and the good quality of its soils, our results identified that irrigating a short maize variety would yield similarly to a dryland crop (Figures 15). This result can be explained given the high rainfall at this particular case study from the upper Gilbert catchment (StRonans Station). We hypothesise that as water becomes unlimited for a shorter crop like maize, the crop will be more limited by lack of solar

radiation than by water availability. In contrast, irrigating a longer crop such as cotton would nearly double crop yields (Figure 16). Though similar solar radiation limitations in wet seasons have been reported also on cotton by other researchers.

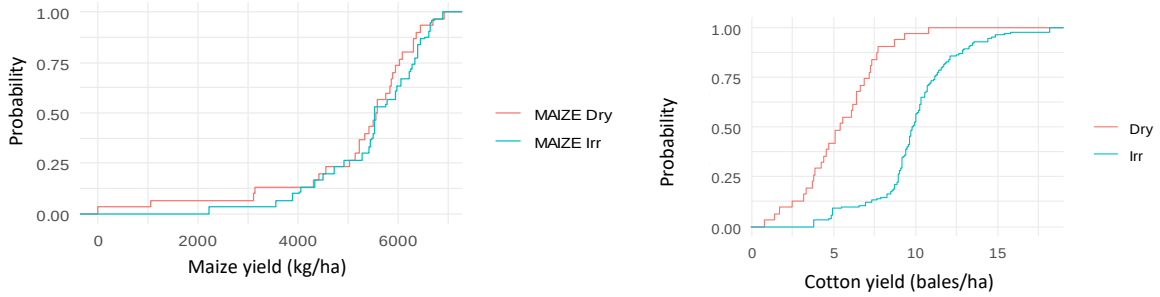


Figure 15. Probability distribution function of simulated maize and cotton yields under dryland and under irrigation for the case study farm.

During one of the discussions, an additional scenario was proposed to the farmer to replace summer maize with irrigated winter maize (sowing window July 1st week). Yields, gross margins and ground cover where then compared. Down-side risk was considered as the likelihood of growing a crop that produced a gross margin lower than $1000/ha. Initial results show that a winter sown maize - cotton production system would be highly profitable compared to the irrigated summer sown maize - cotton production system, i.e., increassing the most likely cumulative gross margins by almost 4000 $/ha. Likewise, as all the irrigated systems, the down-side risks would be reduced from one loss every four years in the dryland system (~25%) to nearly zero (Figure 16).

Table 6. Water-Use Efficiency in $/ML for the co-designed cropping scenarios. Water use efficiency was calculated as average annual gross margin in ($/ha) divided water applied with irrigation (ML/ha).

Scenario	Year 1	Year 2	Year 3	Year 4	$/ML
A (present)	cotton/maize	cotton/maize	cotton/maize	cotton/maize	-
B (msc)	maize/soybean	cotton	maize/soybean	cotton	1203.7
C (mc)	maize	cotton	maize	cotton	1954.9
D (mbc)	maize/barley	cotton	maize/barley	cotton	1978.6
E (mmc)	maize/mungbean	cotton	maize/mungbean	cotton	1661.9
F (wintermc)	cotton/maize	cotton/maize	cotton/maize	cotton/maize	2218.7

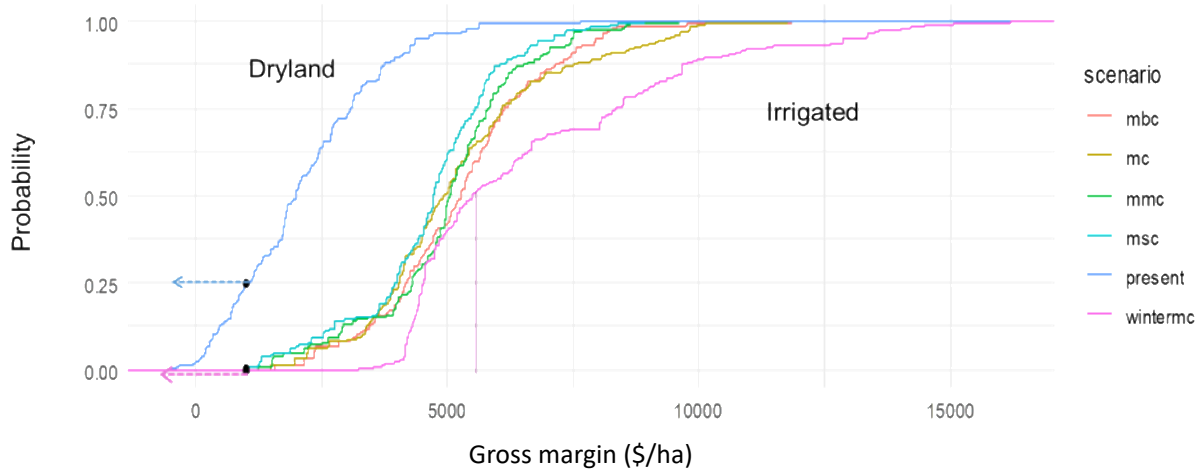


Figure 16. Probability distribution function for the average gross margin calculation of the current dryland rotation, and co-designed irrigated diversification scenarios. The arrows on the y axis show the down-side risk, or probability of achieving a gross margin lower than 1000 $/ha for the current summer maize – cotton, and irrigated cotton-winter maize rotation. The vertical pink line indicates the highest median gross margin, which is for the irrigated cotton - winter sown maize rotation.

Maintaining ground cover was considered an important and sought sustainability and productivity trait for the different cropping systems. Lack of ground cover was early identified in the co-design process as a weak point of the present system (A). Ground cover is low as cotton stubbles are removed immedieately after harvest. The converse is true for maize where the stubble is left on the ground. The farmer interest was to design cotton based rotations able to maintain ground cover during the whole year. Discussed scenarios included adding irrigation to the current system (B), integrating an irrigated winter crop - barley (C), and a summer pulse legume, soybean (D) or mungbean (E), as double crop after cotton, while the researchers proposed to grow the maize under irrigation in winter in a cotton maize rotation (F). The irrigated winter maize and cotton rotation was expected to increase and keep high values of ground cover over fallow periods, increase the cropping intensity, and probably mitigate to some extent the incidence and need for multiple sprays for fall armyworm. In addition, the water use efficiency of the system was expected to also increase.

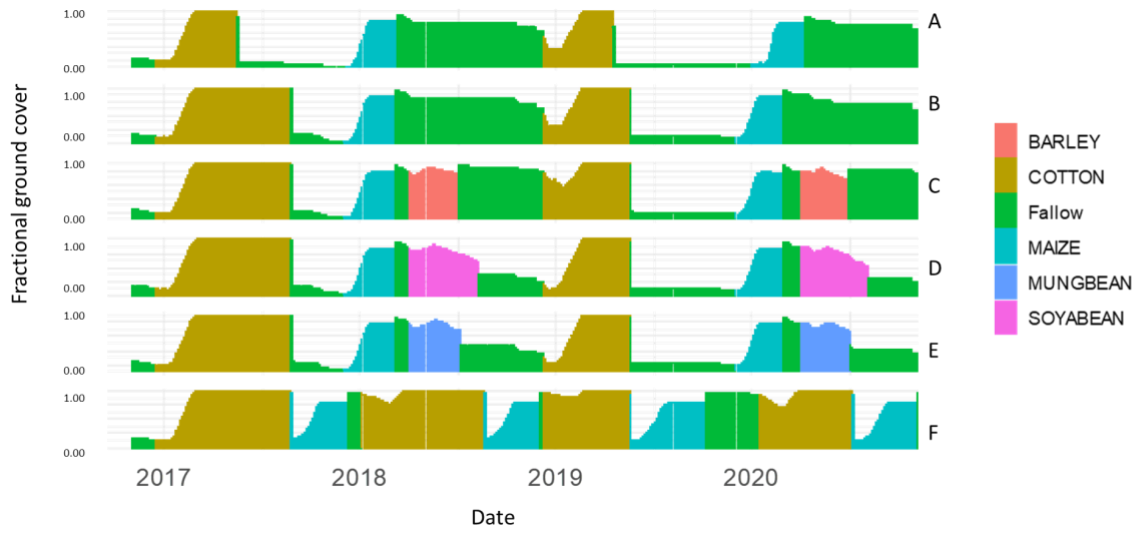


Figure 17. Time series over a four-year rotation for the fractional ground cover for the current and co-designed cropping system scenarios. Rotations are labelled as in table 6.

Since all the proposed systems are irrigated, the farmer was interested to compare the economics in terms of dollars per megalitre of applied irrigation water. As expected, irrigation more than doubled the profitability of the system and dramatically reduced down-side risks. Though of particular interest was the researchers' proposed cotton – winter sown maize rotation. Table 6 shows that the cotton – winter sown maize rotation will provide the largest water use efficiency values in terms of gross margin per unit of water use, the largest median gross margin (Figure 16), and the lowest chance of crop failure (Figure 16). The next step will involve discussing with the participating farmer conducting a winter sown maize trial at the farm to confirm the viability of the system.

Preliminary conclusions

The researchers and the case-study farmers have been working together to co-design several alternative crop production systems for a case-study farm in the upper Gilbert catchment area. It was observed that the involvement of the researchers and farmers in the co-design process and the use of fore-sighting techniques aided using the APSIM model allowed us to have informed discussions and quantified options across multiple farmers' objectives. In-depth discussions with farmers will continue help identify and design cropping systems that are more profitable, sustainable, and resilient.

Needs for further research and development

1. Results to date highlight that improving rainfall infiltration into the soil and crop root extraction of the moisture stored in the soil during extended periods without rain is the best opportunity for sustaining profitable cropping systems across Northern Australia.
2. New sorghum cultivars show important fit to the mixed cropping and grazing farming systems of the north. Though significant bird damage needs to be expected until there is significant area developed across the region.
3. Maize, sorghum, cotton, pulses and even irrigated winter cereals and pulses all need to be considered in the development of more diversified cropping systems that are better integrated with the local main industries – beef grazing and feed lotting. There are two main reasons for this (i) diverse sources of income will increase resilience, and (ii) a larger number of commodities will avoid the saturation of a limited market with a single commodity. One of the main issues farmers in North Queensland face is the lack of markets, and if all the farmers would just grow sorghum and cotton or maize and cotton, the sorghum and maize market of the Tablelands would saturated very quickly.
4. In terms of agronomy and based on our results so far, future investment needs to focus on a whole farm approach that develop diversified and resilient farms businesses; practices that increase rainfall harvesting and permanent ground cover; irrigated cropping systems that include both irrigated winter and dryland summer crops; novel crop nutrition options, and amelioration options for sub soil constraints.

Communication activities

During the extent of the project multiple communication activities did take place. These included, field walks, one to one discussions, the distribution of annual trial reports, phone and zoom discussions, webinars, the production of an update on sorghum agronomy for the Gilbert, a project website, and newsletters.

Project webpage

The list of project documents, webinars, newsletters and the Sorghum Agronomy for Northern Queensland Update can be downloaded from the project webpage https://www.qld-fsr.info/de-risking-cropping-in-northern-aus

Media and Social media report

- An ABC Land Line episode featured Prof D Rodriguez who explained the procedures followed when Fall Army Worm was detected and identified at one of the trial sites can be accessed here:

  https://www.abc.net.au/landline/hungry-caterpillar:-fall-armyworm-hits-australian/12122370

- The team has continued using social media (Twitter @Queensland_FSR) to raise awareness on the project objectives and project progress.