SPRING PLAINS NSW
WEDNESDAY 20 JULY 2022

GRAINS RESEARCH UPDATE

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GRDC 2022 Grains Research Update Welcome

Welcome to the first of our northern GRDC Grains Research Updates for 2022.

For the last two years, we've had to alter plans to host these updates virtually but thanks to the easing of COVID-19 pandemic restrictions, we're finally able to have everyone back to listen to our research, development and extension (RD&E) updates in person.

The northern region has had its fair share of challenges this year. While seasonal conditions have improved and provided reprieve for growers, advisers, agronomists and researchers, parts of New South Wales and Queensland have had to battle the implications of excessive rainfall and wet conditions.

Untimely rain has forced many growers to alter their operations and look at how they can do things differently to work with the wet conditions. Despite the difficulties, feedback from growers has still been optimistic with most supporting the notion of there being more money in mud than dust.

With that positive mindset comes a need to provide the latest information and advice from grains research and development. There's also been a significant push from the industry to make more informed management decisions to ensure productivity isn't impacted by the increasing costs of inputs.

We would like to take this opportunity to thank our many research partners who have gone above and beyond normal expectation this season to extend the significant outcomes their work has achieved to growers and advisers.

For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual GRDC Updates, which bring together some of Australia's leading grains research scientists and expert consultants. We trust they will help guide your on-farm decisions this season and into the future.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers. To this end, GRDC has established the National Grower Network Forums and I encourage you to look out for these forum opportunities in your local area.

GRDC has also placed significant importance on having staff in the regions – whether it be travelling to events like this or being based in our regional offices across the country, including Toowoomba and Wagga Wagga.

We feel more connected to the industry than ever when we are out in the regions and encourage you all to take any opportunity to engage with us to help inform our important RD&E portfolio.

If you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
Gillian Meppem
Senior Regional Manager – North

SPRING PLAINS
GRDC Grains Research Update
Wednesday 20 July 2022

Spring Plains Hall

Registration: 8:30am for a 9am start, finish 2:50pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**Cereal foliar disease management in 2022 -** pathotype and varietal issues	Steve Simpfendorfer (NSW DPI)
9:35 AM	**Matching canola variety with environment and management -** time of sowing, flowering windows, and drivers of phenology	Jeremy Whish (CSIRO)
10:00 AM	**How well does canola fit into northern farming systems?**	Lindsay Bell (CSIRO)
10:30 AM	**MORNING TEA**	
11:00 AM	**Comparing the performance of different farming systems** - gross margins, water and nitrogen use efficiency. - The benefits of summer crop to the system and how does cotton compare to grain sorghum? - Farming system nutrient legacies – impacts on N inputs, cycling and recovery of applied fertilisers	Jon Baird (NSW DPI) & Lindsay Bell (CSIRO)
12:00 PM	**Crop sequence impacts on root lesion nematodes, charcoal rot, AMF, and crown-rot**	Steve Simpfendorfer (NSW DPI)
12:30 PM	**LUNCH**	
1:20 PM	**How soil organic matter and carbon work -** data from 500 paired sites across the northern region	David Lawrence (DAF QLD)
1:50 PM	**Carbon sequestration options for grain producers in NSW -** pros, cons & pitfalls	Katie McRobert (Australian Farm Institute)
2:25 PM	**Discussion** ○ Managing crown-rot west of the Newell ○ Soil organic carbon in continuous cropping systems ○ Upcoming nutrition & crop sequence decisions and strategies	Tim Poole (Poole Ag Consulting) & Brad Coleman (Coleman Agriculture)
2:50 PM	**CLOSE**	

Contents

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Compiled by Independent Consultants Australia Network (ICAN) Pty Ltd.
PO Box 718, Hornsby NSW 1630
Ph: (02) 9482 4930, Fx: (02) 9482 4931, E-mail: northernupdates@icanrural.com.au

Northern region wheat stripe rust epidemic in 2021 – learnings for 2022

Steven Simpfendorfer[1], Robert Park[2], Mumta Chhetri[2]

[1] NSW DPI Tamworth
[2] The University of Sydney

Keywords

fungicide management, varietal resistance, pathotypes, head infection, green bridge

GRDC codes

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI (Project BLG208) and UOS1801-004RTX

Take home messages

- A significant stripe rust epidemic occurred in 2021 across much of northern grains region
- Good cropping years are usually also good for rust infection. The green bridge, an early start to stripe rust infections and mild conditions allowed additional rust lifecycles, which all led to higher inoculum and infection in 2021
- Slow crop development in mild conditions left some crops unprotected between typical management growth stages and delayed onset of adult plant resistance
- Varietal resistance can vary considerably between the key pathotypes (strains) of stripe rust and there was an increased distribution of the 239 pathotype in 2021, which resulted in some unexpected varietal responses
- Predicted La Niña conditions, on the back of 2021 seasonal conditions, is likely to support another stripe rust epidemic in 2022 but steps can be taken to reduce risk and improve management.

Why was there a problem in 2021?

Good cropping years are usually 'good' (i.e., bad) rust years! These pathogens make a living off live plant tissue, so the more vigorous plant growth is, the better the substrate for rust pathogens. Typically, vigorous plant growth occurs in years with good moisture, which is also conducive to rust infection.

At least six hours of leaf wetness is needed for a stripe rust spore to germinate and infect the leaf blade. Once established, further disease progression is purely dependent on temperature. The optimum temperature range for stripe rust development is 12-20°C. At these temperatures it will take 10-14 days for a fresh batch of spores to emerge from infected leaves. This is called the latent period, during which time stripe rust infection within leaves is not visible. Temperatures above or below this optimum range DO NOT kill the pathogen. Rather the fungus slows and can become dormant outside these temperatures, but importantly will continue to develop once temperatures return to the optimal range. Hence, the more time in a 24-hour period between these optimum temperatures, the shorter the latent period. Conversely, as temperatures normally warm in spring the stripe rust fungus stops developing during the day once above 22°C but continues again overnight as temperatures drop. In these circumstances, the latent period extends to a 20+ day cycle time.

Consequently, the frequent rainfall and extended mild temperatures well into spring across much of the northern grains region in 2021, favoured infection and multiple lifecycles of stripe rust. These conditions created an extremely high pressure season for stripe rust across this region.

Did slow crop development change disease impact and does nutrition play a role?

Seasonal conditions not only affect the stripe rust pathogen, they also affect crop development and expression of resistance genes in different wheat varieties. Most varieties rely on adult plant resistance (APR) genes for protection from stripe rust, which as the name implies, become active as the plant ages. Consequently, all varieties, unless rated resistant (R), are susceptible as seedlings and move towards increasing resistance as they develop and APR genes become active. The growth stage at which APR becomes active differs between wheat varieties and relates to their resistance rating. An MR variety would generally have APR active by growth stage (GS) 30-32 (early stem elongation), MR-MS by GS37-39 (flag leaf emergence), MS by GS49-60 (awn peep-start of flowering) and MSS by GS61-75 (flowering to mid-milk). Varieties rated S or worse have relatively weak levels of resistance that are generally of limited value in disease management. Note that a variety can have a higher or lower resistance rating to individual pathotypes (aka strains) of the pathogen, depending on its resistance genes and the corresponding virulence of different stripe rust pathotypes.

Mild temperatures during 2021 that extended well into spring slowed crop development, which consequently delayed the expression of APR genes whilst also favouring multiple lifecycles of stripe rust infections. This extended time between growth stages also affected management strategies, which in more susceptible varieties is based around early protection with fungicides until APR within a variety is reliably expressed.

For example, in MS varieties a two-fungicide input strategy normally provides effective management of stripe rust, with flutriafol on starter fertiliser or in-crop fungicide application at GS30-31 being the first input, followed by a second fungicide application at GS39. This strategy relies on extended control of in-furrow flutriafol (normally out to GS37-39) or approximately three-weeks leaf protection from a foliar fungicide applied at GS30-31. With a two-spray strategy the GS30-31, application provides three weeks protection of the flag-2 leaf and lower leaves to limit stripe rust development in the canopy. Over the next four to five weeks, the flag-1 and flag leaf will emerge and be unprotected (but should also be under reduced risk of disease due to the first fungicide application). A second application at full flag emergence (GS39) then provides a further three weeks protection of the top three leaves, so that when the heads emerge in four to five weeks and APR becomes active, there has been little opportunity for stripe rust development in the canopy. However, in the milder 2021 season, gaps between key growth stages became extended as crop development slowed resulting in longer periods where the leaves were exposed to stripe rust infection using this traditional two-fungicide input strategy. In milder seasons, more susceptible varieties potentially require a third fungicide input to provide full overlap of protection across susceptible growth stages.

Higher levels of nitrogen nutrition can also delay crop maturity and expression of APR genes within varieties whilst also being more conducive to stripe rust infection (thicker canopy and leaf nitrate food source for pathogen). Differences in nitrogen nutrition can relate to rotation history (pulse vs cereal/canola in previous season) and rate and timing of fertiliser application (pre-sowing, at sowing or in-crop). However, under higher levels of N nutrition the resistance level of a variety only ever drops by one category; it does not for instance make a MRMS variety an S. Under high levels of N nutrition growers need to manage a variety as one category lower in resistance (i.e. manage a MRMS as an MS).

Did the rust in 2020 contribute to the problem in 2021?

All rusts, including stripe rust, are biotrophic pathogens. This simply means they need a living host in order to survive, including between cropping seasons. Volunteer wheat over summer and into autumn provides this living host for stripe rust survival and is often referred to as a ‘green bridge.’

A number of factors dictate the extent and importance of green bridge carry-over between seasons. Firstly, the amount of stripe rust within a season increases the probability and likely level of infection in volunteer wheat plants in the following non-cropping phase. Hence, elevated stripe rust levels in 2020 increased green bridge risk in 2020-21. Summer rainfall is also important for the germination and infection of volunteer wheat plants over summer and into early autumn. The actual resistance of the variety grown also contributes to its importance as a green bridge host, with only a few volunteer plants of a susceptible variety required to survive over summer to produce millions of stripe rust spores, which can then infect autumn sown wheat in the next season.

In eastern Australia in 2021, stripe rust was detected on May 25. This is significantly earlier than the 40 year average of July 13 and was a good indicator of significant green bridge survival. The years in which we have experienced early disease onset have generally been the worst for stripe rust, emphasizing the importance of green bridge control.

Has the stripe rust pathogen changed again in 2021?

Work at the University of Sydney's Plant Breeding Institute Camden revealed the emergence of three new wheat stripe rust pathotypes in 2021, all involving mutations of the 198 pathotype. Extensive comparative greenhouse testing with these new pathotypes has shown that they pose no greater threat to current wheat cultivars than the existing 198 and 239 pathotypes.

Differences in stripe rust levels between various production areas in 2020 and 2021 and in the reaction of varieties between seasons can largely be explained through the varying distribution of existing stripe rust pathotypes in each season. For example, the 239 pathotype was an exotic introduction to Australia, likely from Europe, and was first detected in 2017 at two locations in Victoria. 239 was not detected at all in 2018, at one site in Victoria in 2019 and at 15 sites across NSW in 2020 (7.6% of isolates).

However, there was a large increase in the frequency and distribution of 239 across the northern region in 2021, with 44% of isolates identified as the 239 pathotype. Hence, a variety (Vixen⦶ for example) that is MSS to the 239 pathotype but MRMS to the other two main pathotypes (198 and 134) appears more susceptible to growers in 2021 than it did in 2020.

In these cases, the variety itself has not changed – it is simply that the 239 pathotype of stripe rust, which can cause significant levels of disease in Vixen⦶, has increased prevalence and distribution this season. Additionally, the limited distribution of the 239 pathotype until 2021 means that data on the vulnerability of wheat varieties to it have been limited. The more common occurrence of 239 in 2021 has enabled better data on varietal response to be captured, and so the resistance ratings of a number of varieties are likely to now change. It is important to use the most recent disease ratings when making variety decisions.

How do I know if I'm growing a suitable variety and where do I find the most recent resistance ratings?

NVT online (nvt.grdc.com.au) has a Disease Ratings tool (top right). This is an excellent source of the most current variety ratings to the various pathotypes of stripe rust and a wide range of other diseases. The tool allows users to filter by crop, variety and disease with the disease rating results presented in an easy to read comparative colour coded table. The data in this on-line tool is updated by March each year to ensure that varietal responses from the previous season have been incorporated. Growers should be careful when accessing resistance rating data as publications from previous seasons can quickly become outdated and potentially misleading.

There are multiple stripe rust pathotype ratings in the NVT Online disease rating tool – which one do I use?

Multiple pathotypes circulating across the northern grains region in the past two seasons have certainly complicated varietal resistance ratings to stripe rust. The four dominant pathotypes have differing virulence to various resistance genes within wheat varieties. Hence, a wheat variety can have a vastly different reaction to different pathotypes and therefore the management strategy employed by growers should reflect this.

The challenge for growers and agronomists is knowing which pathotype occurs in their region. The 198 (46% of isolates), 239 (44%) and 134 pathotypes (8% 134 Yr17+ and 1% 134 Yr17+27+) were widely distributed in 2021, whereas only two isolates of the 64 pathotype were identified in 2021, one from northern NSW and one from Qld. Knowing this may influence how much emphasis is placed on individual pathotype ratings.

Rust pressure from different stripe rust pathotypes can be quite localised, which is why some agronomists and growers have valued the additional information provided by having access to resistance ratings to the various common pathotypes. For example, the early sown winter wheat variety DS Bennett⦶ is particularly susceptible to the 198 pathotype. Hence, in areas where DS Bennett⦶ is commonly grown, volunteers over summer and early sowing of this variety potentially selects for early dominance of the 198 pathotype.

If the area sown to DS Bennett⦶ decreases over time, then the dominance of the 198 pathotype early in the season may also be reduced. Equally, good early season management of stripe rust in DS Bennett⦶, such as widespread adoption of flutriafol on starter fertiliser, will also assist in reducing early pressure from the 198 pathotype.

Given the widespread distribution of the 239 pathotype in 2021, greater emphasis should be placed on varietal resistance to this pathotype in 2022. Although these newer 198 and 239 exotic pathotypes have dominated in 2021, varietal reaction to the older 134 pathotypes should not be ignored as they were still detected, albeit at low frequencies, in 2021. Pathotype distribution is mapped by the Australian Cereal Rust Laboratory throughout the season (Australian Cereal Rust Survey 2021 Sample Map - Google My Maps), which can be used to tweak in-crop management decisions. Equally, growers and agronomists should seek in-season intelligence of which varieties are developing rust in their local area. This information is a valuable guide as to which pathotype(s) are likely circulating and will potentially impact their crops. The Cereal Rust Lab also publishes periodic Cereal Rust Reports that include information on varietal responses to all three rust diseases along with information on the rust resistance genes each carry.

My Winter Crop Sowing Guide has 2022 East Coast ratings? What is this?

Long-term monitoring of cereal rust pathotypes in Australia has shown that while rust pathotypes migrate periodically between the western and eastern cereal growing regions, there are many pathotypes that occur in the east that do not occur in the west. This means that a variety that is rust resistant in the west could be rust susceptible in the east depending on the resistance genes it carries. For example, currently any variety with the resistance gene Yr17 will be resistant in WA, but vulnerable in eastern Australia. The same situation applies with the leaf rust resistance gene Lr24, which is effective in WA but not in eastern Australia.

The 2022 East Coast stripe rust rating represents the in-field disease response shown by a variety (as measured by pathologists) to naturally occurring stripe rust infection across multiple field sites in eastern Australia in previous seasons. Hence, this rating is influenced by the most abundant pathotypes in the preceding 2021 season, where there was a dominance of 198, 239 and 134 pathotypes. Due to the low frequency (0.6%) of the 64 pathotype it is excluded from this combined East Coast rating.

The unexpected increase in prevalence of the 239 pathotype in 2021 resulted in the 2021 East Coast rating (which was based on 2020 field reactions), not being a good indicator of field performance for some varieties with greater susceptibility to this pathotype.

The 2022 East Coast ratings will reflect the change in distribution of pathotypes in 2021 and as a result the East Coast rating of some varieties has changed. It is for this reason that pathologists always recommend consulting current disease guides, which are updated annually.

What crop stage do these disease ratings relate to?

Varietal ratings relate to the combination of seedling (all stage) and adult plant resistance genes. The ratings are based on a variety's visual reaction to different pathotypes in replicated field experiments conducted across Australia annually under the NVT pathology system. This GRDC invested project then provides a national consensus rating each year. So, in essence, the disease rating relates to how a variety will react to stripe rust throughout the growing season.

How does varietal resistance work and what is seedling resistance versus adult plant resistance?

Like animals, plants have evolved an immune system that protects them against invading pathogens. COVID-19 has taught us that animals (humans) can develop this immunity through exposure and vaccination. In plants however, this immunity is determined at 'birth' and broadly speaking is based on genes that either:

- Detect the presence of a pathogen and trigger a defence pathway (so called immune receptors). This resistance is usually effective at all growth stages and is known as all stage resistance (ASR; also referred to as 'seedling' or 'major' resistance). While very effective, ASR genes are those that are usually overcome by new rust pathotypes acquiring virulence.
- Slow pathogen growth by 'starving' it. This resistance is effective at adult plant growth stages only and is known as adult plant resistance (APR; also referred to as minor gene resistance). APR is often durable, but incomplete in the protection it provides.

Where a variety only carries an ASR gene and this is overcome by a new rust pathotype, its resistance rating may change from resistant to very susceptible.

Adding another dimension of complexity, many wheat varieties carry a combination of ASR and APR genes. Having both ASR and APR genes means a pathotype change can result in a slight increase in susceptibility when the ASR gene is overcome by a new pathotype, but the APR gene(s) is still effective in providing 'back-up' resistance.

New varieties have been impacted by stripe rust - has resistance broken down?

When a variety becomes more susceptible to stripe rust than previously experienced, it should be remembered that nothing has changed with the plants themselves. It is the pathogen that has changed. Either it has mutated to overcome a resistance gene, or a new exotic pathogen has been introduced. There is currently no evidence to indicate that what we have seen in 2021 is due to mutating or new pathotypes overcoming varietal resistances. Unexpected responses to stripe rust observed in some varieties this season is likely the result of a change in pathotype distribution (particularly an increase in 239) and climatic conditions (persistence of green bridge, earlier infections, multiple pathogen life cycles and slowed crop development). These factors are described in more detail in the other questions.

Why have varieties with the same rating been impacted to a different extent?

The pathotype infecting individual crops can have a significant impact on the level of stripe rust development. For example, when comparing LRPB Lancer⚘, Scepter⚘ and Vixen⚘ (table below) if sown as strips in an individual paddock they will behave quite differently depending on the pathotype present within the paddock. If the 134 17+ pathotype is present, then Scepterᶲ (MSS) will have more stripe rust development than Vixenᶲ (MS) with little if any development in LRPB Lancerᶲ (RMR).

However, if the 239 pathotype is present, then Vixenᶲ (S) will be impacted the most, followed by Scepterᶲ (MRMS), whilst LRPB Lancerᶲ (RMR) will appear quite clean. If the 198 pathotype is present, then all three varieties will have quite similar low levels of infection, as all are RMR or MR to this pathotype. More than one pathotype can infect an individual crop throughout the growing season with the 198 pathotype dominating early in both 2020 and in 2021, while the 239 and 134 pathotypes generally infected later in the season.

Table 1. Stripe rust rating for LRPB Lancerᶲ, Scepterᶲ and Vixenᶲ depending on pathotype present

Variety	Origin	Year of release	Resistances and tolerances			
			Rust			
			Stripe Rust (2022 east coast) Resistance	Stripe Rust (Yr_134 17+ Pathotype) Resistance	Stripe Rust (Yr_198 Pathotype) Resistance	Stripe Rust (Yr_239 Pathotype) Resistance
LRPB Lancerᶲ	LongReach Plant Breeders	2013	RMR	RMR	RMR	RMR
Scepterᶲ	Australian Grain Technologies	2015	MSS	MSS	MR	MRMS
Vixenᶲ	InterGrain	2018	S	MS	MR	S

Stripe rust management

Is it possible to see where stripe rust has been found?

Rust and pathotype distribution is mapped by the Australian Cereal Rust Laboratory throughout the season (Australian Cereal Rust Survey 2021 Sample Map - Google My Maps). There are a few weeks lag in identifying the pathotype, but locations with variety details are mapped weekly after submission to the Australian Cereal Rust Survey and listed as 'result pending' until pathotype information is available.

Does knowing the pathotype change my in-season management?

This depends on your individual approach, as to whether you will take a worse-case scenario approach to stripe rust management based on a variety's reaction to dominant pathotypes in the previous season, or you wish to be more responsive in-season to timing and differential appearance of pathotypes in your area.

Will APR be enough?

Generally, if a variety has a level of stripe rust resistance below an MR rating then fungicide application is required to minimise stripe rust infection at earlier growth stages until APR is expressed. However, note that all varieties unless rated R are still susceptible to stripe rust infection as seedlings, which normally only occurs in seasons such as 2021 with early high disease pressure.

APR is a very useful control mechanism but if significant stripe rust infection exists within a crop when APR becomes active, this mechanism can strip significant green leaf area killing these existing infections. This is not the best way to use APR within varieties. Fungicide application is required at earlier growth stages to minimise infection levels around the time that APR is expressed so that this genetic protection becomes active without stripping out green leaf area.

When do I pull the trigger on fungicide applications?

There are a number of factors to consider when planning fungicide management strategies, but the aim remains to maximise retention of green leaf area on the top three leaves (flag (f), f-1 and f-2) throughout the season to protect yield potential. Considerations when planning fungicide strategies include:

- Observed level or predicted level of stripe rust pressure in crop or region
- Seasonal conditions in terms of recent/predicted rainfall and temperature which dictates infection events and disease cycle time
- Level of genetic resistance within a variety to different pathotypes and the corresponding need for protection at earlier growth stages (e.g. MRMS likely only requires a single fungicide at GS30 whilst MS requires fungicide at GS30 + GS39)
- Nitrogen status of crop with high N crops having delayed APR expression and more conducive to infection
- Growth stage of crop and whether APR visually active
- Yield potential of crop as fungicide application is always an economic decision.

Like many crop inputs, predictions are that fungicide supplies may be tight or uncertain in 2022. This places more emphasis on variety selection for the 2022 season and growers should consider reducing the areas sown to stripe rust susceptible varieties which are reliant on fungicide intervention to protect yield potential. Increasing the area sown to more resistant varieties that are less reliant on multiple fungicide inputs appears worthy of consideration. This will be even more important if the 2021/22 summer is wet which will favour elevated green bridge carry-over of inoculum leading into the 2022 season.

Is the aim for the plant to be rust free?

Ideally, crops should be managed to avoid significant development of spores within canopies so that fungicides are being used more in a preventative rather than curative approach to disease management. However, it is often impractical in high pressure seasons to expect every leaf to be totally clean. More important is whether the infections appear fresh (yellow and fluffy) or old (orange and drier) as spores can be visible and viable on leaves for 2-3 weeks until they desiccate. Is tissue death evident behind the pustules and is there flecking in leaves adjacent to hotspots or more heavily infected plants? This indicates that APR is active and infections although evident will not progress further. Low levels of infection can still occur in MRMS or even MR varieties, but these will not significantly impact on yield so chasing totally rust free crops may not always be economical.

Grass weeds seem to be covered in rust – do they contribute to the problem?

Potentially yes. Barley grass in particular was infected across most of the northern region with stripe rust in 2021. Barley grass can be infected by two types of stripe rust. This can be either:

- Barley grass stripe rust, which does not infect wheat but can cause mild infection in some commercial barley varieties or

- Pathotypes of wheat stripe rust, which can contribute to additional disease pressure in wheat crops.

Rust came in late to the heads - does this impact yield or quality, and carry over in the seed?

Stripe rust can infect individual spikelets within heads when spores enter through a gap created when the anthers (flowers) are exuded from the head. Hence, it is a fairly narrow period of infection that is unrelated to the level of genetic resistance within a variety. Head (glume) infection does not cause abortion of flowers but spores accumulate at the top of the developing grain and compete for resources. Glume infection can therefore reduce grain size within individual infected spikelets, while the rest of the grain within a head develops normally.

The impact on grain size is dependent on the amount of resources that the seed and stripe rust fungus are competing for during grain filling. In a softer prolonged grain fill period, both the seed and pathogen are likely to obtain the resources they need, with minimal or no impact on grain size. Head infection does not carry over in the seed and spores will die or be less visible as the heads dry down into harvest, with any remaining spores blowing away during the harvest process.

In some situations, despite multiple fungicide applications, the disease seemed to keep progressing – is there fungicide resistance in stripe rust?

The University of Sydney Cereal Rust laboratory periodically conducts fungicide insensitivity testing of bulked up isolates from grower paddocks of the dominant pathotypes. There has been no evidence of fungicide insensitivity in stripe rust in the last three years, but bulk testing of 2021 pathotypes will be conducted in early 2022 to confirm this is still the situation. There are a range of other potential explanations for the situation that was observed in 2021, including:

- Fungicide applications being outside the curative activity phase (if applied more than ~five days from infection, necrosis and pustule formation still occurs)
- Vast difference between preventative vs curative approaches
- Rapid reinfection of crops from spores surviving 2-3+ weeks in hotspots
- Pure quantity of spores blowing freely in the wind, and/or
- Mild temperatures extending the time between growth stages and therefore increasing the length of time that leaves were unprotected by fungicide in traditional fungicide strategies.

Many paddocks were too wet to use a ground rig. Does the application method make much difference to the level of control?

Potentially. As the saying goes 'coverage is king' when it comes to fungicide protection. Ground rigs allow higher water rates to be used and generally provide greater canopy penetration than aerial applications. Aerial applications are also inhibited by structures within paddocks such as trees and power lines, which can result in some areas simply not being able to receive coverage. Stripe rust can continue to cycle within these unsprayed areas and potentially provide a source of inoculum for more rapid reinfection of the crop once the fungicide protection wanes. Ground rigs generally do a better job of even application across all areas sown within a paddock.

Am I likely to see stripe rust again in 2022, and if so, what do I do?

The amount of inoculum in the landscape and predictions of a wet summer (La Niña conditions) suggest that stripe rust could be a problem again in 2022. Minimise early infections by managing green bridge over the summer and autumn period. Understand the level of resistance associated with the varieties you are growing and seek advice on appropriate fungicide strategies to ensure pathogen loads are kept low until such time as APR can be fully expressed. Growers and agronomists can assist in on-going rust surveillance and research by being vigilant with paddock monitoring and submitting samples to the University of Sydney Australian Cereal Rust Survey.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers and their advisers through their support of the GRDC. The author would also like to acknowledge the ongoing support for northern pathology capacity by NSW DPI. Much of this information was originally published in Northern Paddock Practices (November 2021) with feedback and input from Vicki Green (GRDC, Crop Protection Manager – North) gratefully acknowledged.

Contact details

Steven Simpfendorfer
NSW DPI, 4 Marsden Park Rd, Tamworth, NSW 2340
Ph: 0439 581 672
Email: steven.simpfendorfer@dpi.nsw.gov.au
Twitter: @s_simpfendorfer or @NSWDPI_AGRONOMY

Robert Park
The University of Sydney, Plant Breeding Institute, Camden, NSW 2006
Ph: 0414 430 341
Email: Robert.park@sydney.edu.au
Twitter: @PbiCobbitty

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Spring vs winter canola phenology across Australia: Insights for northern NSW growers

Jeremy Whish[1], Julianne Lilley[1], Shannon Dillon[1], Chris Helliwell[1], Matthew Nelson[1], Justin Kudnig[2], Tim Wilmshurst[2], Steve Lamb[2], David Tabah[2] and Karl Schilg[2]

[1] CSIRO Agriculture and Food
[2] Pacific Seeds

Key words

development, vernalisation, photoperiod, thermal time, daylength

GRDC code

CSP1901-002RTX

Take home messages

- Day degrees describe the biological clock within crops
- Several factors affect canola development, so simple day-degree calculations do not describe all development processes
- Published days to flowering may not be relevant beyond the site where they are measured
- Knowing the flowering mechanisms allows prediction of flowering without an on-site trial
- Using site variability across Australia improves knowledge at specific sites.

Background

Canola's diverse genetics allows it to be grown as a short-season spring crop or a long-season winter crop. In Australian cropping regions, avoiding damaging frosts or high temperatures during flowering and pod fill are key to maximising yield and oil quality (Kirkegaard et al 2018). Having confidence that a cultivar will flower when expected, ensures timely management and that crops will flower at the optimal time (Lilley et al 2019). Recent climatic changes and the logistics of planting large areas have resulted in canola being sown earlier. This has seen some cultivars behave unpredictably with flowering occurring earlier or later than expected. Phenology is the term used to describe the development or lifecycle of a plant. Understanding the phenological mechanisms within each canola cultivar allows us to predict when it will flower in different environments (Whish et al 2020), allowing growers to choose better adapted cultivars and management strategies for different environments.

Identifying cultivar phenology

Plants have distinct stages of development and these describe the phenology of the plant. The most common and easily recognised canola stages are emergence, green bud, flowering, podding and maturity (Figure 1).

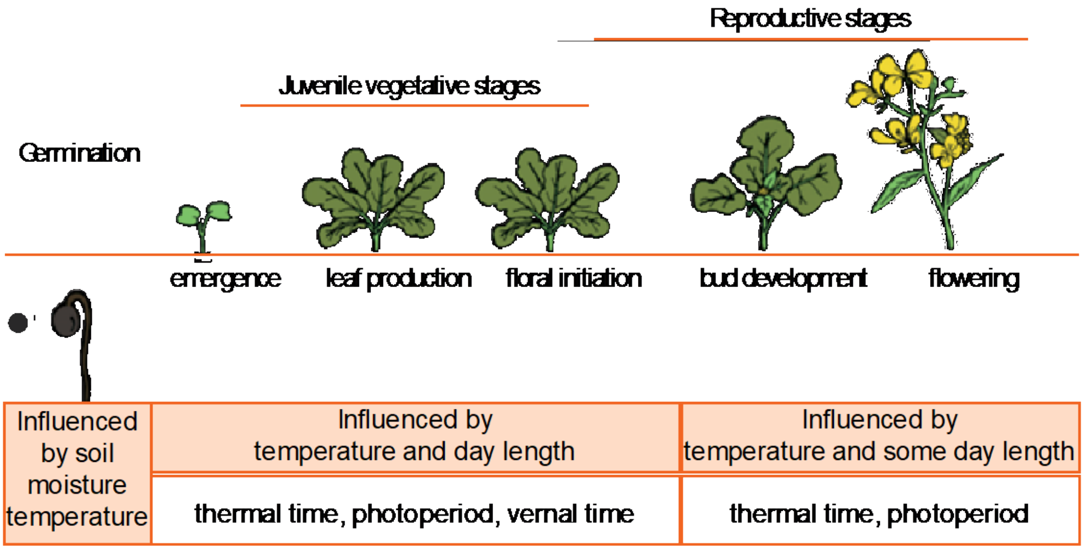

Figure 1. Growth stages for canola and the dominant environmental signals that influence growth in each stage.

Plants respond to environmental signals such as temperature to determine when they move from one developmental stage to another. At the biochemical level, this is caused by specific temperatures inducing the production of plant hormones until a critical concentration triggers the change within the plant. A simpler way to think of this is as a biological clock that accumulates average daily temperatures (day degrees) until a specific target (thermal time target) is achieved.

Why would we want to know this?

Understanding how the environment affects the growth of a plant assists in crop management. Many management decisions are time critical, that is, for optimum results the intervention (spray application, defoliation, stop grazing, add fertiliser) needs to occur before a plant reaches a particular growth stage. Identifying these stages can be difficult, for example, floral initiation can occur well before any visible sign appears in the plant. If the crops are grazed or stressed during this floral initiation period, then a yield penalty can occur (Kirkegaard et al 2008; Sprague et al 2014). Knowing the developmental stage a plant is at can often help prevent yield loss or ensure that untimely management does not occur.

In many environments it is important that canola flowers within a particular window, to avoid frost on one hand and high temperature heat stress on the other (Lilley et al 2019). If a farm is in a region that generally has sowing rain within a particular month, matching the maturity of a variety ensures it flowers inside its optimum window every year. However, in many areas sowing rainfall is unpredictable and may occur too early or too late. Understanding the phenology of different varieties allows selection of specific varieties to ensure flowering occurs at the optimum time and the risk of crop loss is reduced (Figure 2).

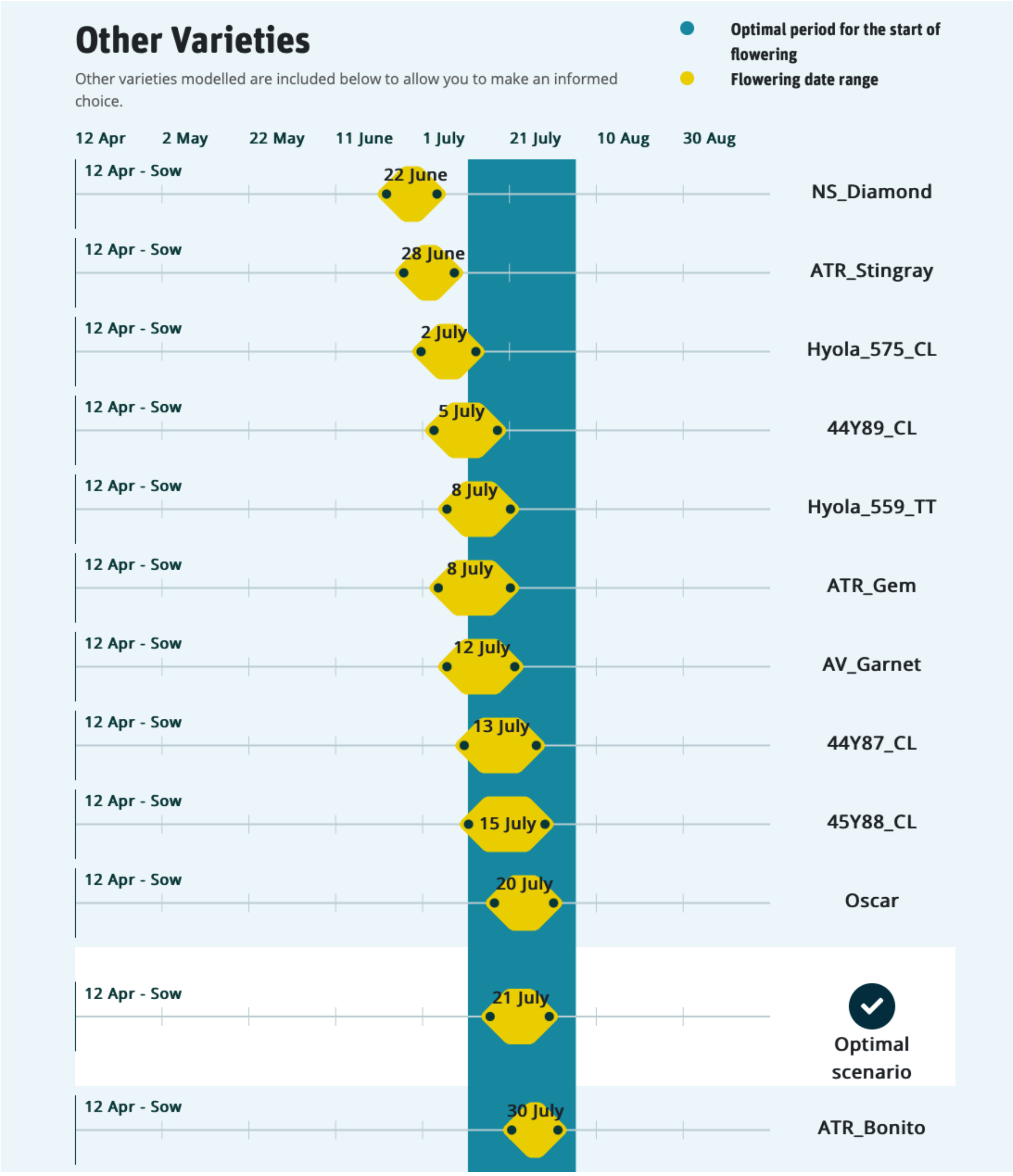

Figure 2. A screen shot from the Canola Flowering Calculator showing flowering data for several cultivars sown in Walgett, NSW on 12 April. At this sowing, short season cultivars NS Diamond, ATR Stingray ⦶ and Hyola® 575CL all start flowering before the optimal starting window while slightly longer-season cultivars like 45y86_Cl and ATR Bonito⦶ start flowering at the optimal time.

Several GRDC projects have contributed to our understanding of canola flowering in the Australian environment. More recently, this work has investigated the gene combinations that produce different flowering responses. The goal is to develop a simple PCR test to predict flowering of new cultivars in any environment. While this genetics work is progressing, companies like Pacific Seeds are using the same phenological testing procedures to ensure they recommend cultivars ideally suited to each region, sowing date and purpose. Pacific Seeds is currently evaluating winter oil seed rape & summer oil seed rape advanced germplasm across Australia in a joint three-year research project with CSIRO. This work is focused on developing a multi-platform interactive application to support management decisions around canola type (winter or spring), time to flowering, crop nitrogen management, grazing and animal health.

How do you calculate the phenological response for a cultivar?

Day degrees, growing degree days, degree days or thermal time are the terms used to describe the units of a plant's biological clock. They are a way of combining time and temperature into a single number. In their simplest form, day degrees are based on the average temperature recorded during a day (Figure 3). To calculate the thermal time target for a plant's development stage, the day degrees are accumulated until a specific target is reached, e.g., variety X accumulates 500-degree days between emergence and flowering.

Simple degree day calculation

$$\frac{\text{Max daily temperature} + \text{Min daily temperature}}{2}$$

date	maxt	mint	dd	cumulative
17/05/2013	20	6	13	13
18/05/2013	18	2	10	23
19/05/2013	18	4	11	34
20/05/2013	18	4	11	45
21/05/2013	18	2	10	55
22/05/2013	12	10	11	66

Figure 3. Simple calculation of day degrees (average daily temperature) and accumulation of day degrees over time to calculate a thermal time target for a change in plant growth stage.

This example is the simplest form and assumes that the plant has a base temperature of 0°C with no growth or development occurring below this temperature. It also assumes that growth and development will continue at high temperatures (>35°C) but this is not always the case.

The simple day degree calculation can be made more complex by identifying those temperatures where plant growth and development occurs and only calculating day degree temperatures when they are within this range. For this paper we use the average daily temperature, but more information and detail on calculating thermal time can be found at: https://www.youtube.com/watch?v=t-8bwU9ke2s

For some plants, development can be described using thermal time alone, as they will flower after accumulating the same thermal time no matter where they are planted. However, canola is more complicated than this, because in addition to accumulating thermal time, it has two other mechanisms — vernalisation and photoperiod, that influence the time to flowering. The combination and interaction of these three mechanisms complicate the process of estimating when canola crops will flower.

Photoperiod (day length)

Photoperiodism describes the response of plants to increasing or shortening day lengths. Long day plants (canola) respond to increasing day length by reducing the thermal time required to flower.

For example, if it takes an accumulated total of 800-degree days to flower during a 12-hour daylight day it would take only 700-degree days if there are 16 hours of daylight. However, in Australia, canola is generally grown with <12-hour daylengths, so daylength does not influence flowering in most commercial crops.

Vernalisation

Vernalisation is described as low temperature promotion of flowering (Salisbury and Ross 1969). It is similar to photoperiod, in that vernally sensitive cultivars require less thermal time to flower when grown in a cold environment. However, there are two types of vernalisation 'facultative' and 'obligate'. Facultative vernalisation is when canola grown in cooler climates require less thermal time to flower than when grown in warmer environments. Obligate vernalisation occurs in winter canola and works like a switch with the plants remaining in a juvenile or vegetative state until about 13 days of vernal time have accumulated (this is 13 days with an average temperature of 2°C or 52 days at 12°C). Obligate vernalisation is the mechanism that keeps plants dormant during European winters, or in Australia make this type of canola good for forage or as a dual-purpose crop. Once the obligate vernalisation trigger occurs, the plant behaves similarly to a spring type - often displaying a facultative vernal response to additional cold.

How do we know this?

By studying the climate of different regions, we can build a set of key environments to test for vernal responses in canola cultivars (Figure 4).

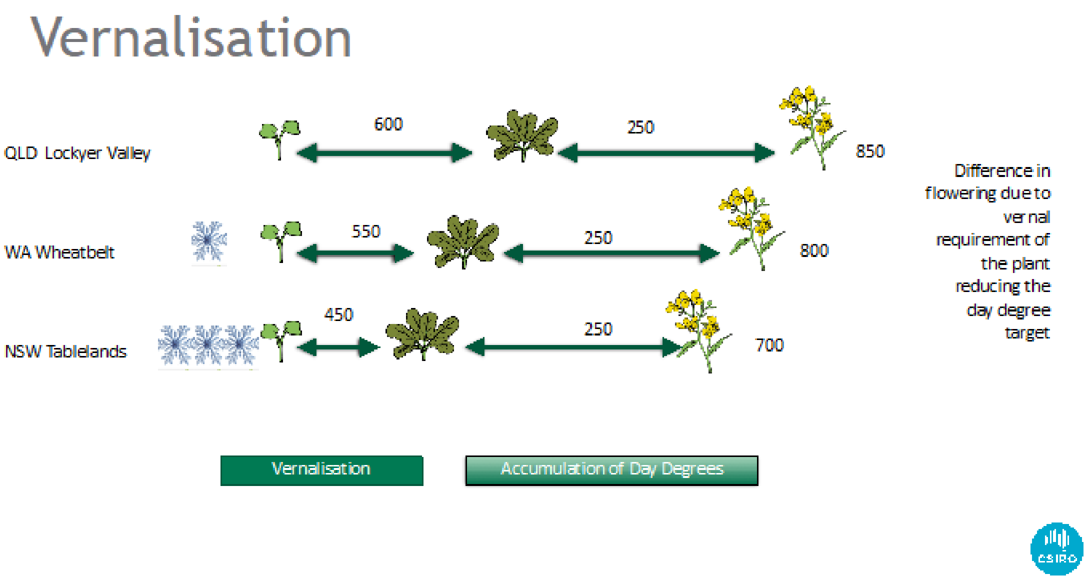

Figure 4. The influence of different rates of vernal accumulation from three sites across Australia on canola flowering time. Cooler regions require less thermal time than warmer regions to achieve flowering.

By strategically choosing sowing dates and sites that accumulate thermal and vernal time differently, we can calculate how each cultivar will behave in any environment (Figure 5). This selection of sites extends from the very cold extremes of the eastern tablelands, to areas with minimal cold, to capture all of Australia's canola growing regions.

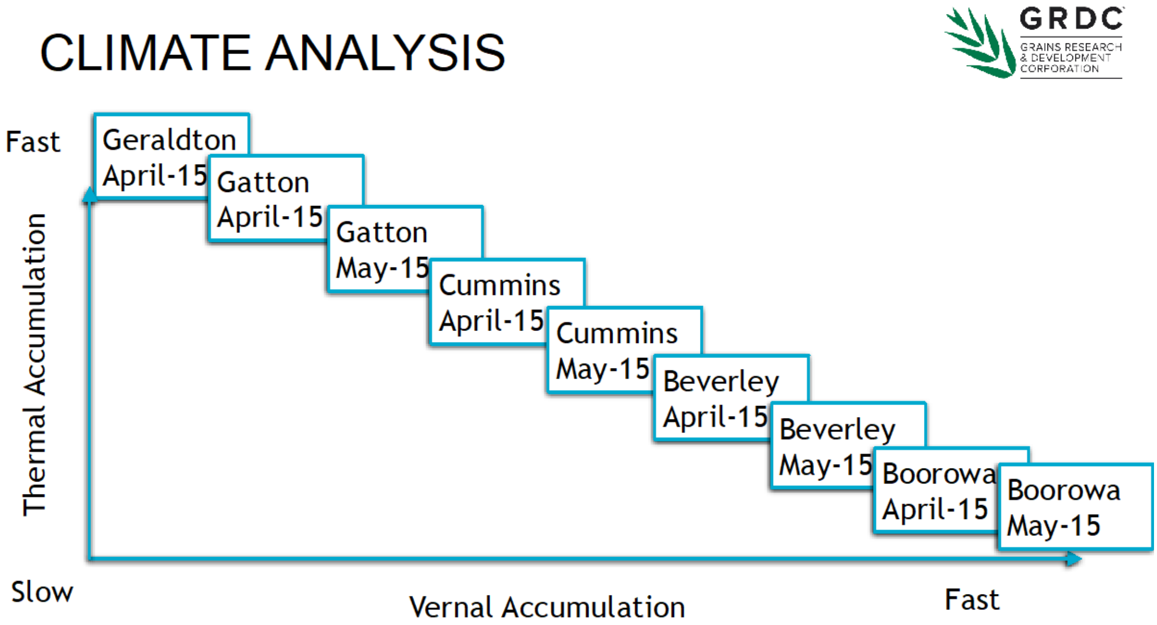

Figure 5. A selection of sowing dates and sites used to characterise the vernal to thermal ratio for Australian canola cultivars.

CSIRO's GRDC funded canola genetics project (Optimising Canola Production in Diverse Australian Growing Environments: CSP1901-002RTX) has used this approach to examine more than 300 different cultivars from around the world. The results demonstrate it is possible to identify different vernal responses (Figure 6).

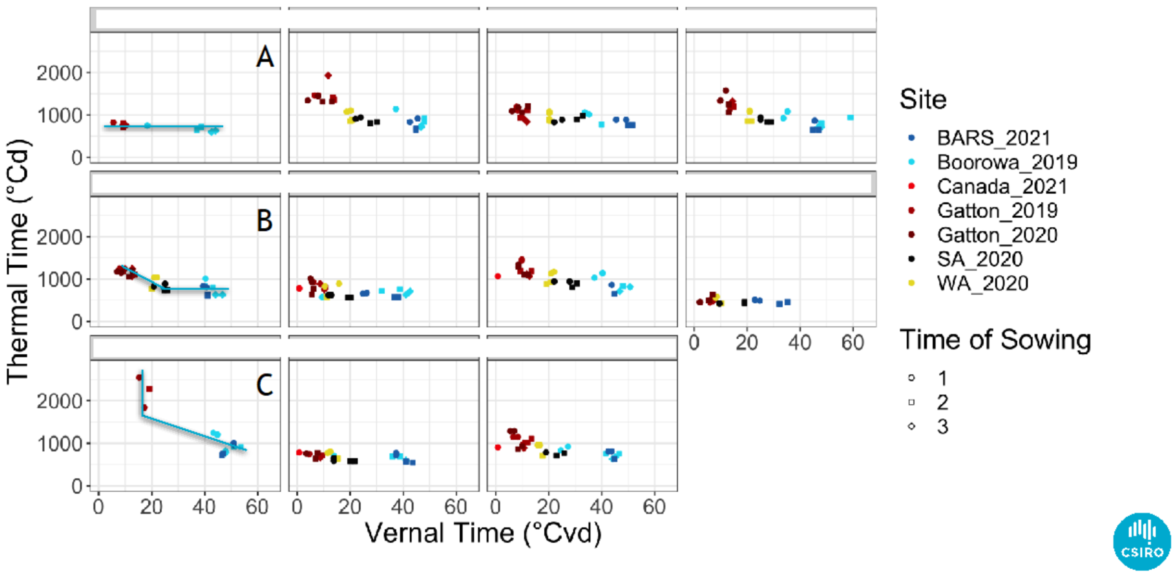

Figure 6. Data from the canola genetics project CSP1901-002RTX detailing three different vernal responses: A. no vernal response, B. facultative vernal response C. obligate vernal response.

How is this being used?

Pacific Seeds is working closely with CSIRO to assess the performance of pre-released canola material (Figure 7). The information collected will improve canola recommendations and ensure obligate winter types are not being recommended for early sowing in areas that receive insufficient vernal temperature. The data from the first year shows the pre-release lines CL210042, CL200026, CT210046 and CL90009 have contrasting vernal response patterns compared to the established cultivars of Hyola 970CL and Hyola 575CL. Such differences can be exploited to match agronomic practices to different environments.

On the tablelands of eastern Australia, the use of long-season varieties for dual-purpose cropping has become popular, but using these same cultivars without grazing has not generated the same profits. The obligate vernal response of winter type canola enables long grazing, but this is limited to areas with long periods of cold temperature. Reducing the size of this obligate response could expand the areas where dual-purpose cropping could be practised and move it away from the cold of the south-eastern tablelands and towards the cool of the slopes and plains.

Dry sowing is a valuable logistics tool especially in areas like WA, but if the season breaks early, sowing a short-season crop may result in early flowering, and if the break comes late, a mid-season cultivar may flower too late. By understanding the vernal response of different cultivars, the so-called 'goldilocks' cultivars can be found, with enough vernalisation to hold them back if sown early, but also able to flower more quickly when sown late. This is less of an issue in the northern NSW as the narrow optimal flowering window restricts the choice of cultivars and sowing date.

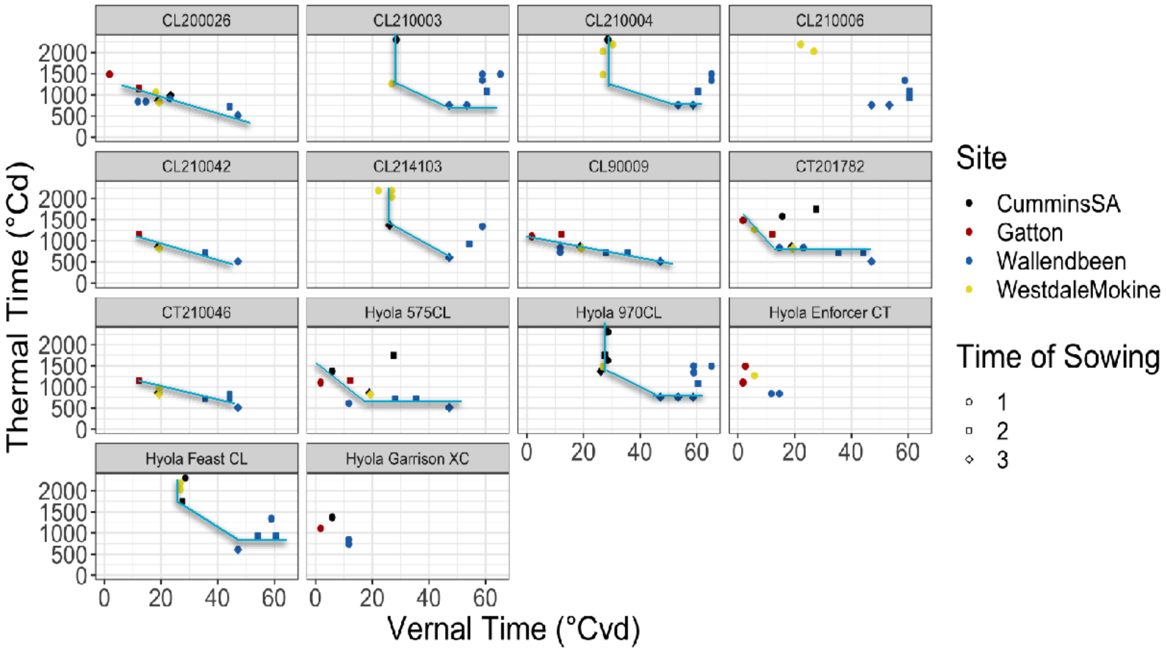

Figure 7. Pacific Seeds pre-released lines showing similar vernal responses to some established hybrids Hyola 575CL and Hyola 970CL along with a more linear response seen in CL210042, CL200026, CT210046, CL90009.

Conclusion

Understanding crop phenology enables the behaviour of crops in different environments to be better predicted and flowering patterns to be more easily calculated (as with the canola flowering calculator). It is hoped that the research described here will reduce the time needed to determine the flowering response of new cultivars. This will enable models like APSIM to use historic climate records to describe variety-by-sowing-date combinations that maximise yield production in different regions. In addition, agronomic practices that are crop-stage dependent, such as spraying or grazing, can be modelled for each area in real time to help improve management and overall grain returns.

References

Kirkegaard, J.A., Lilley, J.M., Brill, R.D., Ware, A.H., Walela, C.K., 2018. The critical period for yield and quality determination in canola (Brassica napus L.). Field Crops Res. 222, 180–188. https://doi.org/10.1016/j.fcr.2018.03.018

Kirkegaard, J.A., Sprague, S.J., Dove, H., Kelman, W.M., Marcroft, S.J., Lieschke, A., Howe, G.N., Graham, J.M., 2008. Dual-purpose canola—a new opportunity in mixed farming systems. Aust. J. Agric. Res. 59, 291. https://doi.org/10.1071/AR07285

Lilley, J.M., Flohr, B.M., Whish, J.P.M., Farre, I., Kirkegaard, J.A., 2019. Defining optimal sowing and flowering periods for canola in Australia. Field Crops Res. 235, 118–128. https://doi.org/10.1016/j.fcr.2019.03.002

Salisbury, F.B., Ross, C.W., 1969. Plant physiology, The Wadsworth botany series. Wadsworth, Belmont, Calif.

Sprague, S.J., Kirkegaard, J.A., Graham, J.M., Dove, H., Kelman, W.M., 2014. Crop and livestock production for dual-purpose winter canola (Brassica napus) in the high-rainfall zone of south-eastern Australia. Field Crops Res. 156, 30–39. https://doi.org/10.1016/j.fcr.2013.10.010

Whish, J.P.M., Lilley, J.M., Morrison, M.J., Cocks, B., Bullock, M., 2020. Vernalisation in Australian spring canola explains variable flowering responses. Field Crops Res. 258, 107968. https://doi.org/10.1016/j.fcr.2020.107968

Acknowledgements

This work builds on work conducted as part of the GRDC, CSIRO funded Optimising Canola Production in Diverse Australian Growing Environments: CSP1901-002RTX and the ongoing canola research between Pacific Seeds and CSIRO.

Contact details

Jeremy Whish
CSIRO, St Lucia Qld
Ph: 0428 763 426
Email: Jeremy.Whish@CSIRO.au

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How well does canola fit into northern farming systems?

Lindsay Bell[1], Jeremy Whish[1], Steven Simpfendorfer[2], Jon Baird[2], Kathi Hertel[2], Andrew Erbacher[3]

[1] CSIRO
[2] NSW DPI
[3] DAF Qld

Key words

canola, soil water, nitrogen, rotation, risk, disease, root lesion nematodes

GRDC codes

DAQ2007-002RTX, CSP00187, CSA00050, DAQ00192

Take home messages

- Canola offers a range of rotational benefits for disease management, weed management, and the potential to widen sowing windows
- Understand when canola would most likely fit into your system to maximise its benefits and mitigate its risks – that is, when you should put it in your mix of crop choices
- Farming system data shows significant opportunities for canola, but risks are still significant
- Canola won't suit all situations – several aspects need to line up to mitigate risk and maximise benefits. Critical aspects to consider include:
  - Soil water at sowing – threshold of > 150 mm in most locations to mitigate risk of low crop yields
  - Sowing window – understand your optimal sowing window to manage the risk of frost and heat stress during critical periods
  - Disease or weed issues – use canola where you are going to reap the benefits in subsequent years (e.g., winter grass problems, high *Pratylenchus thornei* nematode populations)
  - Ensure sufficient N is available – avoid situations with low starting soil N, as this will be difficult to address in northern systems with applied fertilisers at sowing or in season.
  - Preceding crops – be cautious of crops that host sclerotinia which increases disease risk (e.g., chickpea)
  - Following crops – use canola leading into disease-sensitive crops/varieties, N availability is likely to be a little higher than after cereals, consider following with another break crop, i.e., a 'double-break' to 'reset' the system.

Introduction

Northern farming systems are challenged by a lack of reliable break crops that offer effective weed management options and help with reducing soil-borne diseases such as nematodes, Fusarium crown rot, and charcoal rot. Canola is one winter crop option that provides these benefits. Canola is a highly profitable staple crop in southern farming systems and a range of historical work has explored the wider potential of expanding its use further north (see Holland et al. 2001, Robertson et al. 2004). However, canola has traditionally been perceived as a risky crop in northern farming systems due to the greater frequency of high/low temperatures during grain filling, which often result in significant yield, quality and oil content downgrades.

Despite this history, there is now a wide range of varieties that fit a diverse range of niches in the farming system, ranging in phenology (or growing season length) to fit different sowing windows, and herbicide tolerance packages. Alongside improved planting equipment with better depth control, these advances address some of the limitations to using canola more widely in northern grain systems.

Recent research in the 'Optimising Canola Profitability' project has established a range of extension material to help guide the management of canola crops in the north, covering; crop planning and preparation, matching varieties with sowing dates, crop protection, nutrition, and harvest management (see 20 Tips for profitable Canola). The paper compliments this information by addressing the questions; 1) Is it worth it – what is the opportunity vs the risk? 2) When and how would it fit into my system? 3) What are the likely legacy impacts I need to consider?

Crop reliability & risk mitigation

Sowing opportunities & establishment

As canola has relatively small seed that must be planted shallow (<40mm depth), this limits the duration of the sowing window to plant into surface moisture. The reliability and frequency of suitable sowing events in the right window for canola can be a critical constraint to incorporating it more reliably into northern farming systems. Below (Figure 1) we compare the frequency that a sowing event is likely to occur in different fortnightly windows through autumn at a selection of locations. A sowing event is defined as a rainfall event exceeding potential evaporation over a 7-day period. This shows that in more temperate, winter dominant rainfall locations where canola is widely used (e.g., Young), a sowing opportunity occurs during mid-April to mid-May in over 70% of years. In contrast, in northern NSW and southern Qld, with less and more variable autumn rainfall, the frequency of this sowing event is significantly lower at around 40-50% of years. Whilst this is likely to limit the frequency that canola could be effectively established in the north, it does show that in around half the years we are likely to still receive conditions that should allow canola to be sown in a viable window. This also shows that at many of our locations there are often sowing opportunities in early April (about 1-in-4 to 1-in-5 years), which may allow longer season canola cultivars to be used.

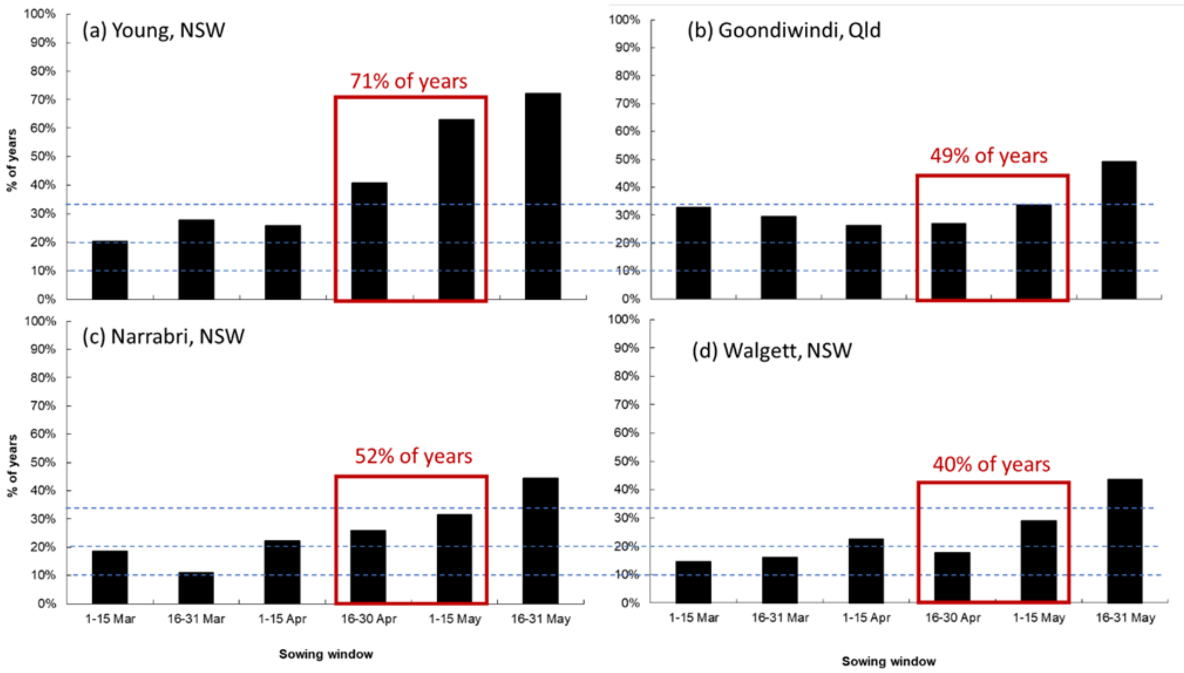

Figure 1. Historical (1956-2015) analysis of frequency of a sowing event (i.e. rainfall exceeding evaporation over 7 day period) across fortnightly sowing windows comparing a southern NSW site (Young) with 3 northern locations. The red box depicts the optimal canola sowing window in late April and early May and the total frequency that such an event occurs in this period.

Crop yields and soil water use

As part of the northern farming systems research sites over the past 6 years, canola has been grown on 9 unique occasions across southern Qld, central NSW, and northern NSW under a diversity of seasonal conditions (see Table 1). This provides a useful snapshot of what might be expected for canola performance in the northern region. From these sites, 3 of the 10 site-seasons achieved low yields (<0.5 t/ha), which were attributable to a frost event during early pod-fill (Narrabri 2017) and very dry conditions after sowing in 2019, when less than 200 mm of water (as rain or stored water) was available to the crop throughout the season. Five of the 9 site-seasons achieved grain yields of 2.5-3.5 t/ha, which occurred under conditions where the crop had access to over 350mm of water during the season. Most of these crops started with soil profiles >60% full prior to reaching the sowing window, which contributed around 30% of the water used by the crop. This was augmented by additional in-crop rain at around the long-term average winter season rainfall across these locations (i.e., 200-300mm) except for Trangie in 2020 on a Red soil with a low plant available water content (PAWC), these high yielding crops all started with >150 mm of PAW prior to sowing. The harvest index (0.23-0.27) and grain water use efficiency (WUE) (≤ 8.0) measured in these studies were less than those that are typically expected in more traditional canola-growing regions.

Table 1. Canola crop productivity (grain yield and biomass produced) & water used across farming systems experiments conducted 2015-2021.

Site-Year	Year	Yield (t/ha)	Biomass (t/ha)	Harvest Index	Water used (mm)	Pre-sow PAW (mm)	Biomass WUE (kg DM/mm)	Grain WUE (kg DM/mm)
NARRABRI	**2017**	0[A]	8.0	0	320	146	25	0
NOWLEY	**2019**	0.21	1.9	0.10	183	53	10	1.1
TRANGIE RED	**2019**	0.44	1.8	0.25	139	22	13	3.2
BILLA BILLA	**2018**	1.46	6.0	0.24	255	114	24	5.7
TRANGIE GRAY	**2020**	2.70	13.6	0.20	403	148	34	6.7
TRANGIE RED	**2020**	2.94	10.8	0.27	371	63	29	7.9
NARRABRI	**2016**	3.06	10.5	0.29	642	225	16	4.8
PAMPAS	**2021**	3.18[B]	16.5	0.19	392	205	42	8.1
PAMPAS	**2015**	3.55	15.2	0.23	517	152	29	6.9

[A] – Frost damage during early podding; [B] – Mouse damage removed 10-20% of pods.

Predicted yields and soil water

As shown in Table 1, seasonal variability and the availability of soil water at sowing are key drivers of yield expectations for canola in the northern region. In particular, soil water at sowing is far more important than in southern environments which receive more reliable winter rainfall. Figure 2 (below) highlights the extent to which different starting water conditions impact yield potential for canola in some example northern locations. This shows that the median yield increases by about 0.5 t/ha for every 50mm of extra PAW in the soil profile at sowing. To achieve a canola grain yield potential of >1. 5t/ha (a benchmark break-even yield under typical price-input scenarios) in >60% of years, soil water at sowing would need to exceed 150mm at Mungindi or Goondiwindi and exceed about 100mm at Narrabri. When PAW at sowing is <100mm, the likelihood of achieving grain yields >2.0 t/ha is low (i.e., less than 1 in 5 years at most locations).

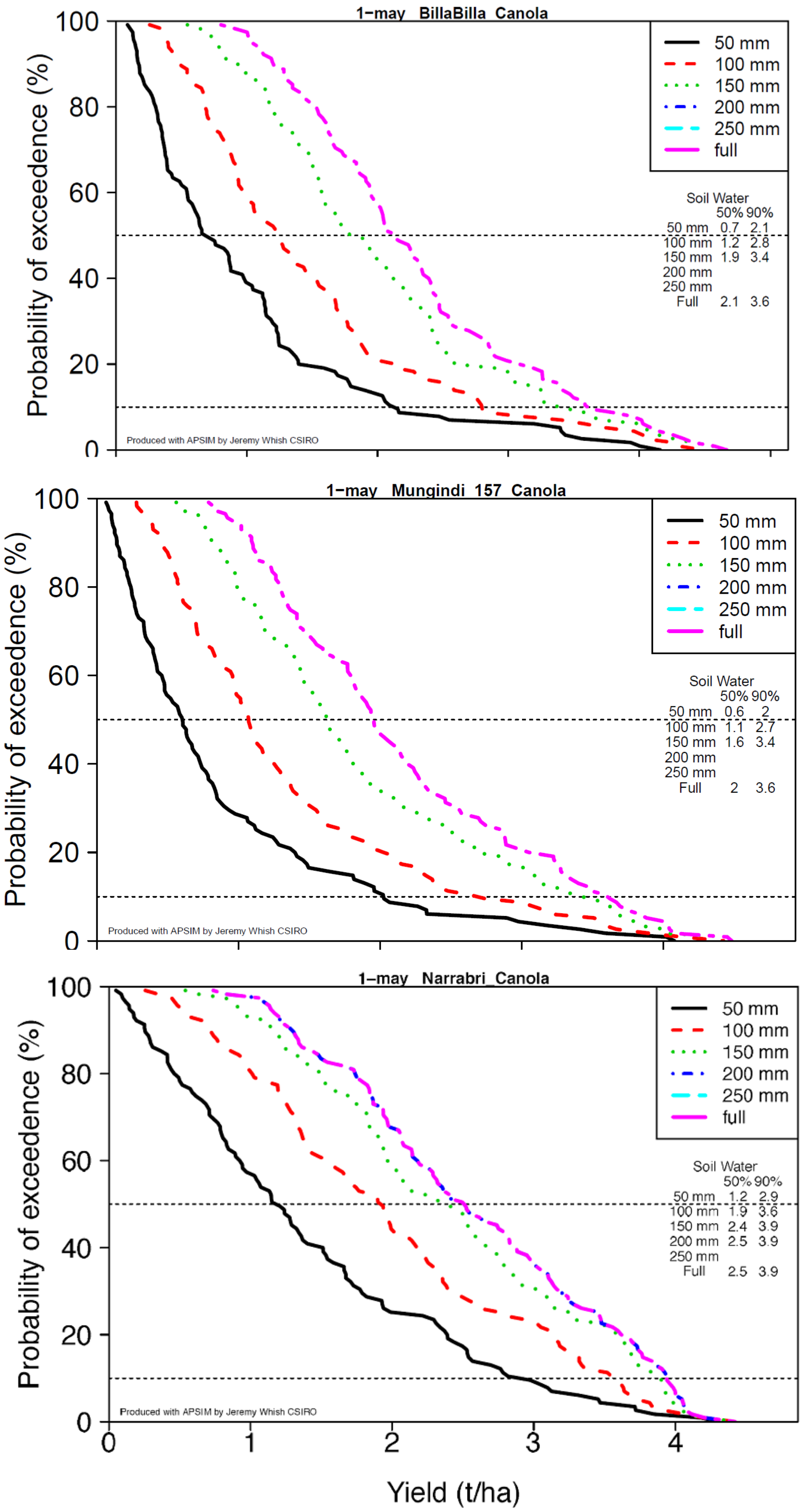

Figure 2. Simulated water-limited yield potential for canola across environments in northern NSW & southern Qld with different plant-available soil water conditions at sowing (indicated by different colours) (Top = Billa Billa, middle = Mungindi, bottom = Narrabri).

Mitigating risk of heat/frost stress

Mitigating the risks of frost and heat stress at flowering is critical for maximising canola yield. In particular, the period 200–400-degree days after flowering (i.e., at peak flowering) is a key stress point when the crop is particularly susceptible to temperature or water stress (Kirkegaard – GRDC update paper Wagga etc). Table 2 (below) shows the predicted optimal flowering windows for canola across various locations in southern Qld and northern NSW compared to a 'typical' canola growing region in southern NSW (Young – shown in bold). Firstly, the optimal window is typically shorter in our northern environments due to a shorter period when frost and heat stresses are minimised. This results in narrow sowing windows for canola to hit the narrow optimum flowering window. Secondly, the optimal flowering window varies significantly across environments – from the earliest situations at Mungindi in the west, to later at Warwick in the east. This means it's particularly important to look at this for your environment and select canola varieties with the appropriate phenology to hit this optimal flowering window for a particular sowing date. These issues can be explored for your location and specific situation using the Canola Flowering Calculator at: https://www.canolaflowering.com.au/

Table 2. Predicted optimal window to start flowering and sowing date for an example variety with early/fast phenology across various environments spanning the northern grains region compared to a traditional canola region at Young, NSW.

Location	**Optimal window to start flowering**	**# Days in window**	**Optimal sow date for an early cultivar (e.g., Stingray)**
Young	**13 Aug – 15 Sept**	**33**	**1 May – 17 May**
Narrabri	18 July – 15 Aug	28	1 May – 15 May
Moree	10 July – 8 Aug	29	26 Apr – 10 May
Goondiwindi	6 July – 2 Aug	27	20 Apr – 3 May
Walgett	12 July-6 Aug	25	26 Apr – 8 May
Mungindi	26 Jun- 23 July	27	19-26 April
Warwick	2 Aug -25 Aug	23	12 May – 20 May
Condamine	17 July – 12 Aug	26	3 May-15 May

Nitrogen management

Canola has a high nitrogen demand compared to other crops. Hence, understanding the nutrient status of paddocks planned for canola production is likely to be of particular importance to maximise yield potential. Current recommendations are to budget 70-80kg of N per tonne of target grain yield. So, for a 2.5 t/ha grain yield, a canola crop needs to have access to at least 175kg of N/ha. Relying on application of fertilisers at sowing to meet this large demand can be problematic, particularly in the northern region where in-crop rainfall required to move this fertiliser N into the soil profile is less reliable. There is also a high risk of seedling damage from high application rates of N fertilisers at sowing. Therefore, canola is likely to fit best when sown in situations where there's likely to be significant residual N through the soil profile at sowing. Applying 30-40% of budgeted N as a top-up around stem elongation is recommended to spread the N application out and enable N inputs to be adjusted to seasonal conditions.

Performance and legacy of canola compared to other crops

At various farming system sites, canola has been grown under comparable conditions to other winter crops, providing insights into its relative performance in terms of grain yield and legacies such as extraction and replenishment of soil water and N availability in subsequent crops.

Firstly, despite the variability in canola productivity shown above, canola has produced grain yields between 34 and 70% (average of 55%) of those achieved in wheat under the same seasonal conditions. Canola yields have typically equalled those achieved in chickpeas under comparable seasons. Of course, the relative prices and input costs required between these crops will influence a direct comparison of profitability.

Canola left similar amounts of soil water at harvest compared to winter growing cereal crops or grain legumes in the same season. Some small differences (<20 mm) occurred in some seasons where canola left 15-30mm more water than the winter cereals; often due to earlier termination of canola while the cereal was still finishing. Despite there often being a slightly lower fallow efficiency achieved after canola than following a winter cereal, in the seasons with comparisons of PAW at the end of the subsequent fallow, there was little if any significant difference compared to either the cereals or legumes.

One clear and consistent observation was that the nitrogen that accumulated during the subsequent fallow after canola was often 20-35kg N/ha higher than following a cereal. Similar results have been consistently reported in southern regions. This occurs because canola leaf residue has a lower C:N ratio, and hence breaks down more quickly and releases more N than from cereal residues.

Table 3. Differences between canola relative to a winter cereal (wheat, barley) or a winter legume (chickpea, fababean) grown in the same season in terms of grain yield, residual soil water (SW) at harvest, soil water and N mineralised over the following fallow.

Site-Year comparison	Canola yield (%) relative to:		Canola harvest SW (mm) relative to:		Canola SW at sow next crop (mm) relative to:		Canola fallow N mineralisation (kg/ha) relative to:	
	Wheat	Chickpea	Cereal	Legume	Cereal	Legume	Cereal	Legume
Trangie-Red 2019	34		+20		+17		+18	
Trangie-Red 2020	42		-8		-4		+30	
Narrabri 2017[A]	0		+20		+17		+35	
Pampas 2015	68	95	-4	-9	+4	+2	+28	-10
Billa Billa 2018	60	108	+14	+3				
Trangie Gray '20	57	300	+28	-20				
Pampas 2021	70	123						
Narrabri 2016	-	108	-	0	-	-18	-	-10
Spring Ridge 2019	-	-		0		-14		+34

[A] – Frost damage during early podding

Crop rotational implications

Weed and pathogen management

Clearly an important rationale for using canola in a crop sequence is to achieve some rotational benefits such as reducing populations of cereal or legume pathogens (e.g., root lesion nematodes, Fusarium crown rot), providing an alternative weed control option, and/or opportunities for using (or coping with) alternative herbicide chemistry.

Consistent with previous understanding, our farming system data has shown that canola does not host the root lesion nematode, *Pratylenchus thornei* (*Pt*), the main problem species in the northern region. Hence, the population of this pathogen continues to slowly reduce under a canola crop whilst it will increase significantly under host crops like wheat or chickpea. The benefit for supressing *Pt* populations is further enhanced if the period of growing non-host crops can be extended for >24 months (Figure 3). Hence, growing canola in combination with non-host crops like durum wheat, cotton, or sorghum provides an effective mechanism for reducing the population of *Pt* to low levels in problem fields. However, it should be noted that canola is a host of a different root lesion nematode species *Pratylenchus neglectus* (*Pn*) which is more dominant on lower clay content soils in central and southern NSW. Hence, canola is not a good option for lowering *Pn* populations in these regions. Canola has also been shown to be a valuable alternative crop in northern cropping systems to reduce levels of Fusarium crown rot following winter cereal crops (Kirkegaard et al. 2004).

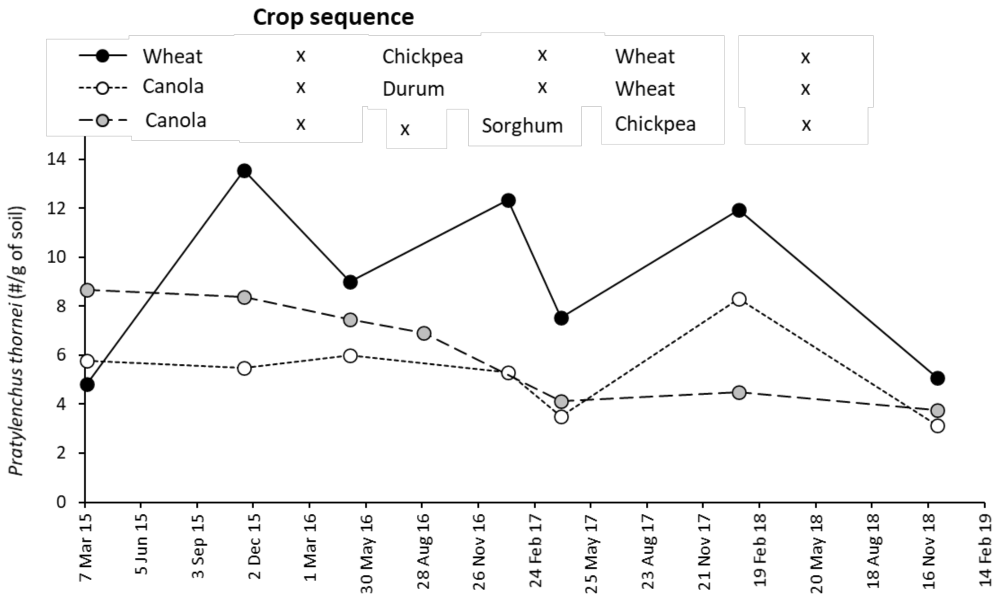

Figure 3. Root lesion nematode (*P. thornei*) populations in the soil over different crop sequences – shows the slow decline in numbers during non-host crops like canola coupled with durum or sorghum to provide a double break, compared to a rotation of host crops like wheat and chickpea.

Other crop rotational impacts/considerations

While canola can offer several positive legacy benefits in a farming system, there are some potential risks to consider in subsequent crop management and selection. Firstly, canola doesn't host beneficial arbuscular mycorrhizal fungi (AMF), so there's a risk that these populations will be reduced during a phase of canola, especially if it is preceded or followed by a long fallow, creating a long period without a host plant. Hence, on sites with low or marginal soil P, it is probably best to avoid following canola with a more AMF dependent summer (cotton, sunflower, mungbean and maize) or winter crop (linseed, chickpea and fababean). Secondly, several herbicides used in canola can have significant plant-back restrictions for some crop choices. This is important to consider in situations with double-crop opportunities into summer crops (e.g., mungbeans, sorghum). Finally, volunteer canola plants, particularly when growing herbicide tolerant canola varieties, can be difficult to control in some subsequent crops and fallows. This can sometimes require more expensive herbicides be used to clean up canola volunteer plants in fallows or control these in the following crop.

Conclusions

Canola offers many potential benefits of crop diversification in a farming system; widening sowing windows, disease and weed management. Both experimental data and modelling suggest there are opportunities to use canola in northern farming systems when we have the confluence of sufficient accumulated soil water and a sowing opportunity in the right window. Whilst these conditions are unlikely to occur every year, they are not infrequent across many environments in the northern grain region.

While considering many of the agronomic considerations outlined above, it is important to also consider the sowing and harvesting equipment available to you. Accurate seed depth control will achieve better and more consistent establishment in canola, and hence sowing machinery that provides this is advantageous. Similarly, accessing a windrower for canola is often challenging and whilst direct heading is possible, it does impose greater risk of harvest losses and requires more attention to timing of harvest to mitigate risk.

References/Further Reading

20 Tips for Profitable Canola: Northern NSW (2019) https://grdc.com.au/resources-and-publications/all-publications/publications/2019/20-tips-for-profitable-canola-northern-nsw

Holland JF, Robertson MJ, Cawley S, Thomas G, Dale T, Bambach R, Cocks B (2001) Canola in the northern region: where are we up to? Australian Research Assembly for Brassicas, Geelong, 2-5 October, 2001. http://www.australianoilseeds.com/__data/assets/pdf_file/0018/4446/CANOLA_IN_THE_NORTHERN_REGION_WHERE_ARE_WE_UP_TO.pdf

Kirkegaard JA, Simpfendorfer S, Holland J, Bambach R, Moore KJ, Rebetzke GJ (2004). Effect of previous crops on crown rot and yield of durum and bread wheat in northern NSW. *Australian Journal of Agricultural Research* 55: 321-334.

Serafin L, Holland J, Bambach R, McCaffery D (2005) Canola: Northern NSW Planting Guide. NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

Robertson MJ, Holland JF (2004) Production risk of canola in the semi-arid subtropics of Australia. Crop and Pasture Science 55, 525-538

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Lindsay Bell
CSIRO Agriculture and Food
203 Tor St, Toowoomba, Qld
Ph: 0409 881 988
Email: Lindsay.Bell@csiro.au

Farming system modifications at Narrabri – legacy impacts on grain productivity, economics and soil dynamics

Jon Baird, NSW Department of Primary Industries

Key words

cropping system, crop legacy, WUE, gross margin

GRDC code

CSA00050 and DAQ00192

Take home message

- Intensifying the cropping frequency increased system grain productivity compared to the base-line grower's practice/sequence. The Higher intensity system which grew nine crops produced 4.0 t/ha more than the baseline system which grew six crops
- The increased grain productivity of the Higher intensity system led to higher fertiliser usage and greater drawdown on residual soil nutrient reserves (in particular mineral N)
- Increasing fallow length to improve planting moisture resulted in lower system grain productivity but higher individual crop yields, leading to the highest system gross margin as high value crops (such as cotton) maximised yield potentials
- Sequencing wheat-chickpea elevated soil populations of the root lesion nematode *Pratylenchus thornei*, to the extent where cultivars that are highly susceptible to this nematode species had to be replaced by more resistant options.

Introduction

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of crop sequences in the northern grains region achieving 75% of their water limited yield potential.

Growers face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Change is needed to meet these challenges and to maintain farming system productivity and profitability. Consequently, Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) are collaborating to conduct an extensive field-based research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability, with the question;

"Can systems performance be improved by modifying farming systems in the northern region?"

In 2014 research began in consultation with local growers and agronomists to identify the key limitations, consequences and economic drivers of farming systems in the northern region; to assess farming systems and crop sequences that can meet the emerging challenges; and to develop the systems with the most potential for use across the northern region.

Experiments were established at seven locations; with a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by DAF and the DPI NSW (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils)).

Table 1. Systems implemented at each of the locations. Trangie has systems applied on both red and grey soils. Pampas includes summer dominant, winter only and mixed opportunity cropping systems. Pampas also includes combinations (i.e., higher legume + diversity) not listed here.

	Pampas (Core site)			Regional sites					
System/ modification	Summer	Winter	Mixed	Emerald	Billa Billa	Mungindi	Spring Ridge	Narrabri	Trangie
Baseline	*	*	*	*	*	*	*	*	*
Higher crop intensity	*		*	*	*		*	*	
Lower crop intensity	*	*	*		*	**	*	*	*
Higher legume frequency	*	*	*	*	*	*	*	*	*
Diverse crop options	*	*	*		*	*	*	*	*
Higher nutrient supply	*	*	*	**	**	*	*	*	*
No. of systems	38			6	9	6	6	6	6

Farming system descriptions

1. **Baseline** is typical of local zero tillage farming systems with approximately 1 crop per year grown using moderate planting moisture triggers of 50% plant available water capacity (PAWC). Crops grown in this system are limited to wheat/barley, chickpea and sorghum. These crops have nitrogen fertiliser applied to achieve 50th yield percentile as determined by the PAW prior to planting and based on APSIM yield simulations for each site.
2. **Lower crop intensity** reflects a conservative rotation to accumulate greater PAW for the next crop (80% PAWC). The same nutrient management as the *baseline* system is applied. Crops grown are also similar to the baseline but may also include cotton as a high value crop at some sites.
3. **Higher crop diversity** allows a greater suite of crops to be grown to better manage disease, root lesion nematodes and herbicide resistance. Planting triggers and nutrition are the same as the baseline system. The unique rules for this system focus on managing root lesion nematodes, with 50% of the selected crops to be resistant to *Pratylenchus thornei,* and 1 in 4 crops resistant to *Pratylenchus neglectus.* To manage herbicide resistance, two crops utilising the same herbicide mode-of-action cannot follow each other. Crops grown in this system include wheat/barley, chickpea, faba bean, field pea, canola/mustard, sorghum, mungbean, maize, millet and sunflower.
4. **Higher legume** aims to minimise the use of nitrogen fertiliser by growing every second crop as a pulse (legume), with a preference for those that produce greater biomass and greater carry-over nitrogen benefits. Crops grown in this system are similar to the *baseline* (wheat/barley, chickpea, sorghum) with additional pulse options (faba bean, field pea, & mungbean). Crops will be fertilised (N) to achieve average yield potential for the PAW, with nitrogen only applied to the cereal crops.
5. **Higher crop intensity** aims to minimise the fallow periods within the system and potentially grow 3 crops every 2 years. Crops will be planted on lower PAW (30%) and have a greater

reliance on in-crop rainfall. Crop choice is the same as the *baseline* system, but with mungbean added as a short double-crop option. These crops are fertilised (N) to achieve average seasonal yield potential for the PAW prior to planting.

6. **Higher nutrient supply** will have N and P fertiliser applied to match the fertiliser requirements of a 90th yield percentile crop; with the risk that crops will be over fertilised in some drier years. This system will be planted to the same crop as the baseline each year, so that the only difference is the amount of nutrients applied.

Method

Field experimental location

The Narrabri farming systems site is located on the University of Sydney's research farm – "Llara". The soil at the site is a brown-grey Vertosol with medium-heavy clay throughout the soil profile (Table 2). The site has high background fertility levels. The PAWC calculated at the site is 210 mm for wheat to a depth of 120 cm.

Table 2. Soil characteristics at Narrabri "Llara" field site.

Depth	Organic carbon	Conductivity	pH	
(cm)	*(%)*	*(dS/m)*	*(CaCl2)*	*(H2O)*
0-15	0.83	0.10	7.47	7.96
15-30	0.55	0.20	8.10	8.86
30-60	0.48	0.28	8.29	9.20
60-90	0.39	0.35	8.56	9.52
90-120	0.30	0.43	8.59	9.49

System evaluation

Over the course of the project life for each system at each experimental site, data was collected on crop yield, input costs including fertilisers, seed, herbicides, pesticides and machinery operations. This allowed calculation of the accumulated income and gross margins for each of the cropping systems deployed at every location. Consistent prices for each commodity (10-year average adjusted for inflation) were used to avoid introducing discrepancies in the data (Table 3). All grain yields were corrected to 12% moisture to account for variable harvest moistures.

$$system\ WUE\ (\$\ GM/mm) = \frac{\sum\{(yield\ x\ price) - variable\ costs\}}{(\sum rain + \triangle\ Soil\ water)}$$

Table 3. Grain pricing used in calculations based on median prices over the past ten years, less $40/t cartage costs, for selected crops.

Crop	$/t	Crop	$/t
Barley	218	**Sorghum**	221
Wheat (durum and APH)	269	**Maize**	281
Canola	503	**Mungbean**	667
Chickpea	504	**Sunflower**	700
Faba bean	382	**Cotton**	1090 ($480/bale lint)
Field pea	335		

Experimental conditions

The climatic conditions experienced during the project were quite variable (Figure 1). The site experience drought conditions from December 2017 to December 2019, and then received higher than average rainfall for the 2020 and 2021 calendar years (703 and 772 mm). In addition, maximum temperatures during the 2016/17 and 2017/18 summers were quite high and resulted in crop stress in summer crops such as sorghum.

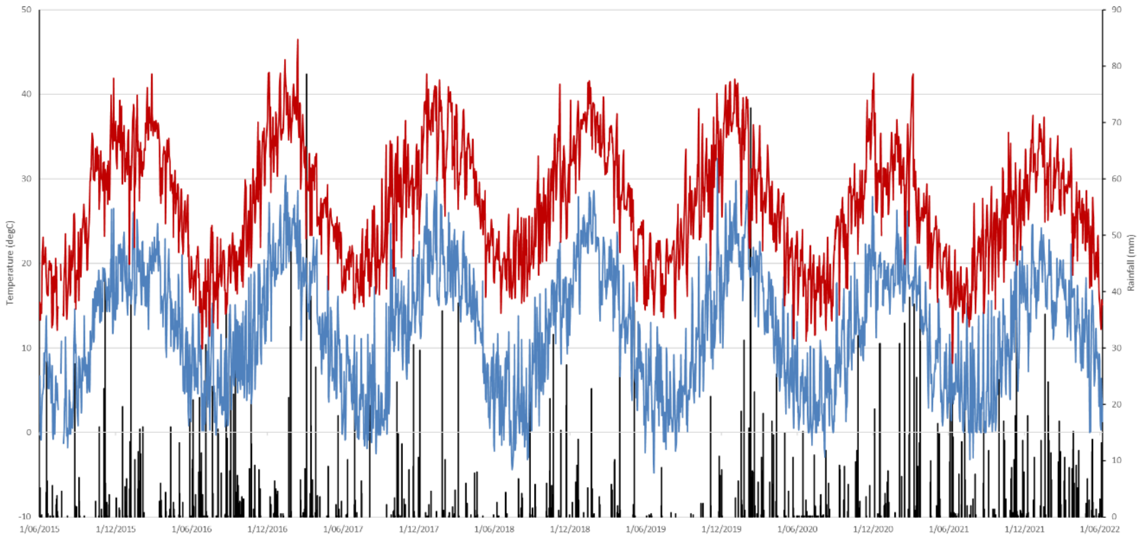

Figure 1. Climatic conditions at Narrabri (2015-2022). The red line denotes daily maximum temperature, blue line is the daily minimum temperature and black columns show daily rainfall.

System rotation

There was a wide divergence in cropping sequences at the Narrabri farming systems site as treatment rules dictated various cropping scenarios (Table 4). The Baseline system – which mimics a 'typical' grower's practice - was dominated with wheat, chickpea and sorghum. The Higher legume system sowed crops in similar seasons to the Baseline, but contained an extra legume crop compared to the Baseline and two fababean crops in the rotation instead of the chickpea in Baseline system. The higher diversity system as expected sowed a wider range of crops including fieldpea, canola, durum wheat, bread wheat and chickpea.

The biggest variation in crop selection and timing was between the Higher and Lower intensity systems. With the Higher intensity containing nine planted crops compared to the Lower intensity which planted four harvested crops and one cover crop. This included the 2021/22 summer season with both systems growing either cotton (Lower intensity) or sorghum (Higher intensity) (Table 4).

Table 4. Farming system cropping sequence at Narrabri (2015-2022).

	Baseline	***Higher nutrient***	***Higher legume***	***Higher diversity***	***Higher intensity***	***Lower intensity***
Winter 15	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Summer 15						
Winter 16	Chickpea	Chickpea	Faba bean	Field Pea	Canola	
Summer 16						Cotton
Winter 17	Wheat	Wheat	Wheat	Canola	Wheat	
Summer 17						
Winter 18						
Summer 18	Sorghum	Sorghum	Mungbean		Sorghum	
Winter 19				Durum	Chickpea	
Summer 19						
Winter 20	Wheat	Wheat	Wheat	Chickpea	Wheat	Wheat
Summer 20					Mungbean	
Winter 21	Chickpea	Chickpea	Fababean	Wheat	Wheat	
Summer 21					Sorghum	Cotton

Project results

System yield

Of the six farming systems at Narrabri, the Higher intensity system had the greatest productivity at 18.5 t/ha (Figure 2). It has produced more than 3 t/ha of grain than the next system (Higher legume – 15.2 t/ha). The higher grain productivity is related to the increase in crop intensity since winter 2021, as the Higher intensity system grew twice as many crops as the other systems during that period (four compared to two or one). The higher cumulative grain production did come at an expense to individual crop yield, as the system did have lower individual season yields compared to the other systems which had longer fallow periods. For instance, the 2021 wheat in the Higher intensity system which followed a summer mung bean crop was lower yielding (4.3 t/ha) than the 2021 wheat crop in the Higher diversity (6.3 t/ha) which had a summer fallow following chickpeas in winter 2020.

Further highlighting the influence cropping intensity has on grain productivity, the Lower intensity system had the lowest cumulative grain yield at Narrabri (11.0 t/ha) (Figure 3).

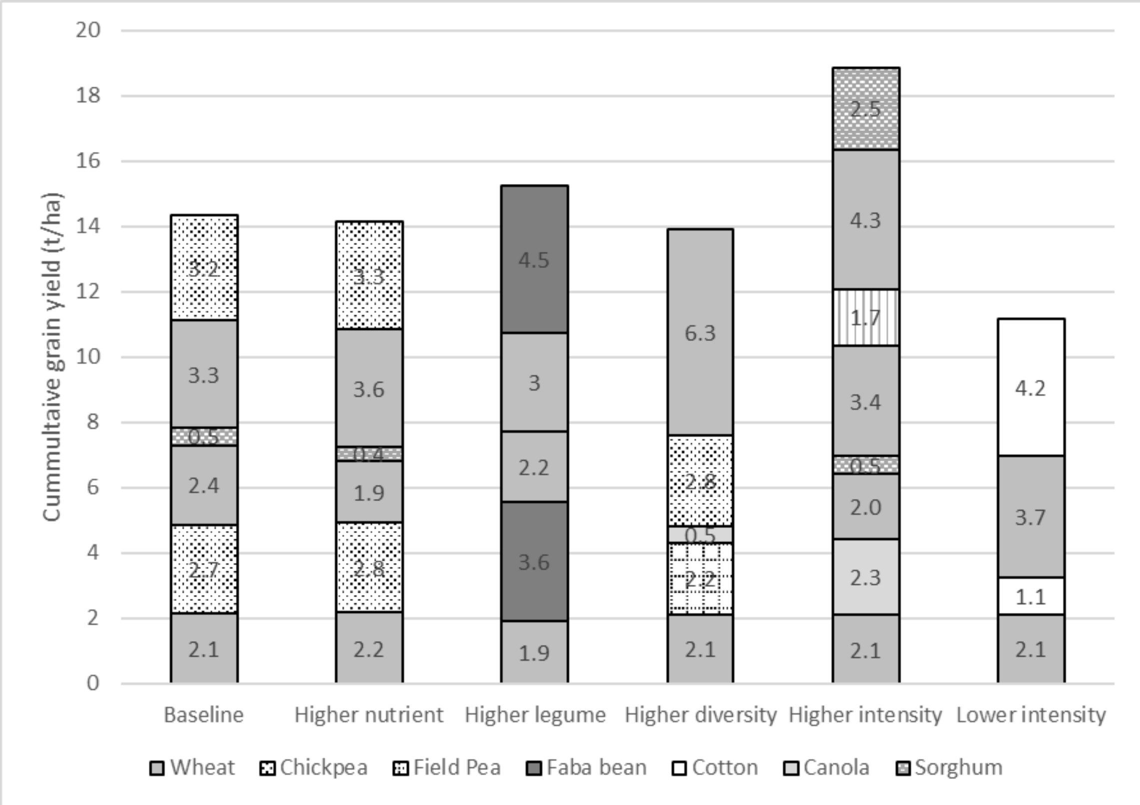

Figure 2. Cumulative farming system grain production at Narrabri, NSW (2015-2022).

System economics

The gross margins for each of the farming systems at Narrabri increased considerably during the last three seasons (Figure 3). The largest improvement coming from the Lower intensity system with a gross margin of $5,801/ha, as the 2021/22 cotton crop achieved the highest returns to date in the project. The Lower intensity system went from being one of the lowest gross margins to the highest due to the returns from the high value 2021/22 cotton crop ($4,455/ha). This system was historically safe in terms of crop returns as there were no failed crops recorded at Narrabri, compared to the other systems which had at least one failed crop (the one crop with negative income in the Lower intensity was a designated sown cover crop).

Of the other systems, the Higher intensity did have the greatest crop income due to the extra sown crops, but growing costs were also highest and therefore overall systems gross margin ($4,049/ha) tracks similar to the Baseline system ($3,775/ha).

The additional fertiliser applied to the Higher nutrient system reduced the overall system gross margin compared to the Baseline system (-$680) (Figure 3). Crop yields from the project showed that water availability had a greater influence on productivity rather than nutrient application, and therefore the higher nutrient system struggled to generate extra yield or income with the higher fertiliser application rates.

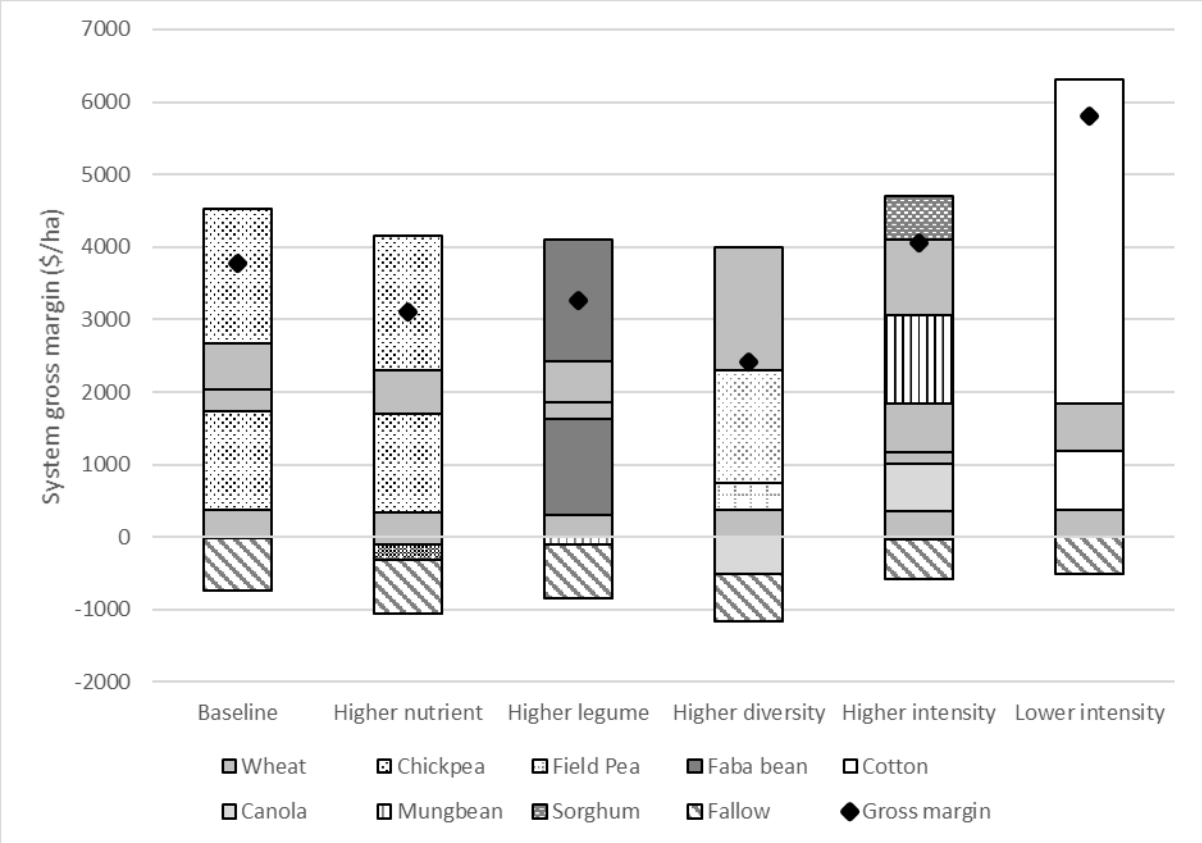

Figure 3. System gross margins and crop returns at Narrabri (2015-2022).

System water use

The Higher legume system had the greatest water use efficiency (WUE) with 6.3 kg/mm/ha at Narrabri between 2015 and 2021 (Table 5). This corresponded with the high grain productivity from the two planted fababean crops (2016 and 2021), highlighting that incorporating legumes into a farming system can improve grain yields and maintain good WUE. Although, one implication of incorporating legumes into the farming systems is the high degradation of plant residue which influences ground cover and thus fallow efficiency. This was evident at Narrabri, as the Higher legume system had a fallow efficiency of 28%, well below the efficiency of the Baseline system (32%).

Both the Higher intensity and Higher diversity systems had similar WUE (5.9 mm/kg/ha), but had contrasting fallow efficiency, as the shorter fallows in the Higher intensity resulted in the highest fallow efficiency at Narrabri at 33%. The Higher diversity system with longer fallow periods (second only to the Lower intensity system) had a fallow efficiency of 28% (Figure 5).

System WUE ($/mm) was highest in the Lower intensity, as the high system returns improved the efficiency compared to the Baseline system by 84%, and by 174% to the Higher diversity system which had the lowest system gross margin at Narrabri.

Table 5. System water use efficiency (WUE as kg grain/mm PAW), fallow efficiency (FE is % of fallow rainfall captured and stored) and System WUE ($/mm is the system gross margin/mm rainfall)

System	WUE (kg/mm/ha)	FE (%)	$/mm
Baseline	5.5	32	0.96
Higher nutrient	5.5	29	0.78
Higher legume	6.3	28	0.83
Higher diversity	5.9	28	0.62
Higher intensity	5.9	33	1.01
Lower intensity	5.2	14	1.7

Nutritional legacy

The project monitored the legacy impact cropping system had through two process, collecting soil analysis pre- and post- crop and via crop export (system export = seed nutrient % multiplied by grain dry weight).

There were two modified systems that resulted in an increase to the application rate of nitrogen (N) fertiliser – Higher nutrient and Higher intensity – compared to the Baseline system. Both systems increased the fertiliser N rates more than 200 kg N/ha over the Baseline system, but only the Higher intensity exported more N from the system (+25 kg N/ha), while the Higher nutrient system had similar export rates to the Baseline system (Table 6).

The value of increasing legumes in the cropping system did influence nutrition dynamics as the Higher legume system had the same amount of N fertiliser applied as the Baseline system, but overall system balance was far greater as there was an extra 114 kg N/ha exported in grain, along with higher phosphorus and potassium levels. These results highlight that although fertiliser use was not reduced, the nutrient dynamics of the farming system can be improved with the introduction of legume crops.

Table 6. Farming system application and export rates of macro-nutrients at Narrabri.

System	Applied nitrogen fertiliser (Kg N/ha)	Exported nitrogen (Kg N/ha)	Mineral nitrogen change 2015-2021	Exported phosphorus (Kg P/ha)	Exported potassium (Kg K/ha)
Baseline	207	345	-99	47	81
Higher nutrient	448	345	-52	47	84
Higher legume	208	469	-77	60	110
Higher diversity	223	352	-87	44	75
Higher intensity	462	370	-93*	64	79
Lower intensity	158	189	41*	47	32

*does not include summer 2021/22 harvest results

Disease/pathogen legacy

PreDicta B® testing for pathogen levels, including *Pratylenchus thornei* (*Pt*) occurred biannually, pre and post every crop. At Narrabri, *Pt* numbers indicated a strong association with farming system treatments based on the individual crops and varieties grown (Figure 4). The crop choice in 2016 had a large effect on *Pt* numbers. Chickpea planted in the Baseline and Higher nutrient systems increased *Pt* numbers by up to five times over the 2016 pre-sowing numbers. The other legumes planted in 2016, field pea in the higher diversity plots and faba bean in the higher legume system, also increased *Pt* numbers, but not to the same extent as with chickpea. Although *Pt* numbers did increase to moderate levels in 2016 within the baseline and higher nutrient systems, there was no yield effect – chickpea yields for both systems were 2.7 t/ha.

P. thornei numbers reduced across all six systems during the 2016–17 summer fallow. Numbers in both the baseline and higher nutrient systems increased slightly during the 2017 wheat crop (LRPB Lancer) which is rated moderately susceptible (MS) to *Pt*. As a result, both these systems had more than three times the *Pt* numbers than the other four farming systems by the end of 2017. Conversely, in the other four farming system treatments, *Pt* numbers reduced during 2017 with levels less than 1.3 *Pt*/g soil by the end of 2017 (Figure 4). With drought-like conditions starting in the winter of 2018, *Pt* soil populations declined across all treatments and remained in the low population category until the end of the first phase of the project (May 2020).

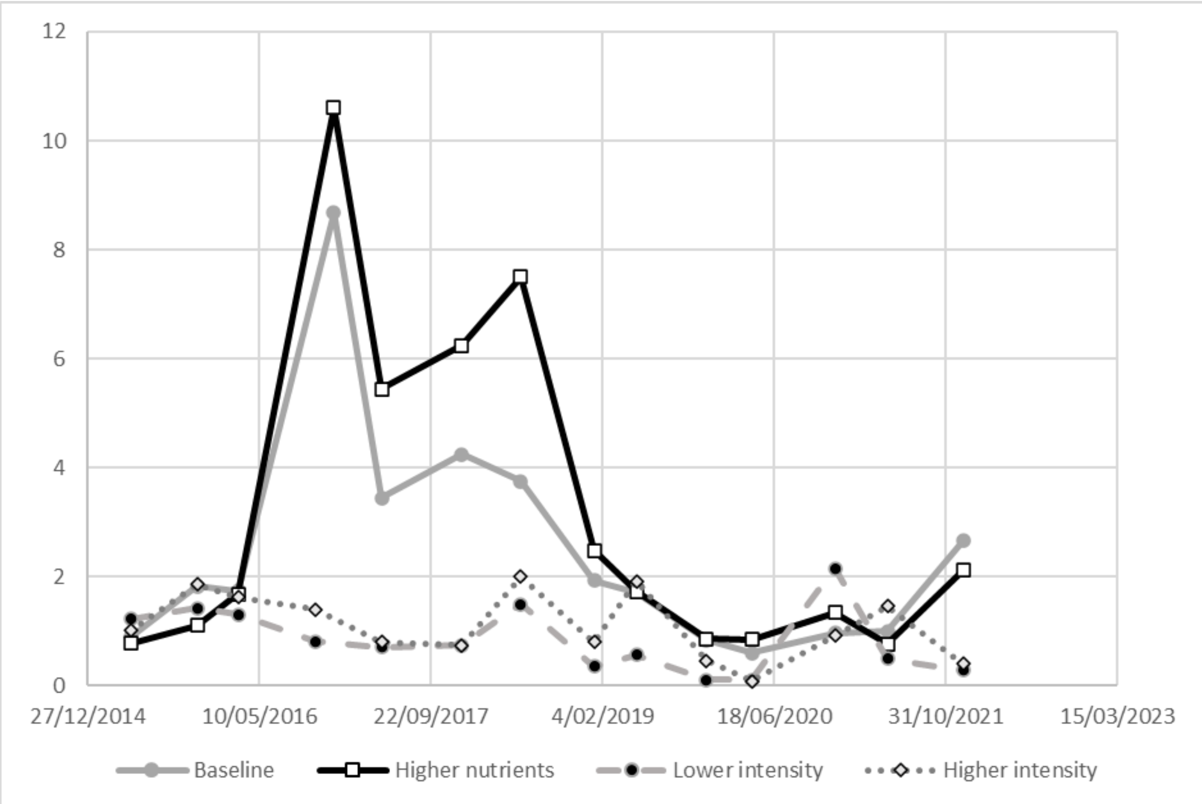

Figure 4. Root lesion nematode *Pratylenchus thornei* numbers at Narrabri across treatments and seasons.

Conclusion

Results from this site demonstrate that growers within the North-west region can modify their current farming systems to achieve greater grain production and/or higher gross margins. This is in part related to modifying planting triggers, as increased cropping frequency with lower soil moisture planting triggers (30% PAW) did improve grain and dry matter production, compared to a moderate planting trigger (50% PAW). In contrast, an even higher planting trigger (80% PAW) led to fewer crops sown during the project life, but the planted crops achieved high yield potential and higher crop value which resulted in greater system gross margin. This means that growers can utilise long fallows to accumulate soil moisture and use that moisture to produce high individual crop yields and better economic results. However, this approach appeared to be very sensitive to using high value crop species (e.g., cotton) to capture the benefit of increased PAW at sowing.

There were legacy implications with increasing the cropping intensity as it led to higher fertiliser use to compensate for increased biomass production and higher grain yield. Although applied fertiliser was greater in the high intensity system, there was still a reduction in background nutrients to a larger degree than the other systems. This in turn may require increased input costs with this farming system to avoid crop yield potential becoming restricted by nutrient deficiencies.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Jon Baird
NSW Department of Primary Industries
ACRI, 21888 Kamilaroi Hwy, Narrabri
Ph: 0429 136 581
Email: jon.baird@dpi.nsw.gov.au

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Updated: Comparing grain and cotton in northern NSW. Impacts on the cropping systems and the advantages of growing summer crops to improve $/mm and as a disease break from winter cereal dominated systems

Jon Baird[1], Lindsay Bell[2], David Lawrence[3], Jayne Gentry[3], Andrew Erbacher[3], Kathi Hertel[1], Darren Aisthorpe[3], David Lester[3]

[1] NSW DPI
[2] CSIRO
[3] DAF Qld

Key words

summer cropping, productivity, economics, soil water use, soil-borne disease

GRDC code

CSA00050, DAQ00192

Take home messages

- Incorporating summer crops such as sorghum and cotton can improve farming returns in terms of $/ha and $/mm
- Sorghum based sequences and winter cropping rotations are very productive and produce higher grain yields, but cotton dominant systems had higher potential system gross margins
- The legacy impact of cotton can last a number of subsequent seasons (especially soil water), so productivity needs to account for the whole cropping system, not the one crop
- When conditions allow for planting moisture, a sorghum/chickpea double-crop does improve gross margins, but there are added risks of planting the second crop compared to cropping after fallow
- Summer crops provided a significant reduction in soil-borne pathogens and nematode numbers, allowing greater choice of crops and cultivars in rotations.

Introduction

The dynamic climate of the northern grains region allows growers to implement diverse cropping systems, from winter dominant to summer cropping including both grain and fibre crops. Hence, there are several options available for grain growers to diversify their crop rotations to help manage disease, weed and herbicide options. Summer crops can generate high-value end products (e.g. cotton), make efficient use of spring/summer rainfall and use nitrogen (N) from mineralisation, which predominately occurs during the warmer months. But there are implications when transitioning into summer crops. Firstly, the length of the pre-plant fallow can elongate when waiting for profile moisture to fill and secondly, the crop legacy impact when returning to winter crops. These implications can decrease the economic gains associated with summer crops and reduce the benefits of a summer cropping transition. There is also the question of how the summer crop will perform? Will the forecasted rain be adequate to achieve yields with high economic returns?

In much of northern NSW and southern Queensland, the pillar summer crops are sorghum and dryland cotton. Dryland cotton requires cropping land to be set aside in a lengthy fallow prior to planting (>10-12 months) to accumulate sufficient moisture to support cotton's long growing season.

Post-harvest operations (e.g., pupae busting) can result in further fallow periods prior to the next crop in sequence. In comparison, sorghum can often be double cropped back to chickpea involving a shorter fallow period and easier transition back into winter cropping. Both sequences were investigated within the farming systems project over the last six years at various points in time and locations. In this paper, we compare the performance of crop sequences involving sorghum and cotton compared with those focusing on winter crops grown over a common period at three sites (Narrabri, Spring Ridge and Pampas). This paper looks at the legacy implication of summer cropping, particularly sorghum and cotton and the implications they may have on a farming system in the northern grains region (NGR) and the economic risks of these systems. The paper details the impacts on nitrogen (N), water use and disease/pathogen levels collected from the northern farming systems project over the last six years.

Farming systems research approach and assumptions

The Northern Farming System project was initiated in 2015 and is co-funded by GRDC, CSIRO, QDAF and NSW DPI, with six regional sites (Qld – Emerald, Billa Billa, Mungindi and NSW – Narrabri, Spring Ridge and Trangie), plus a project core site located at Pampas, Qld. Over the last six years, this project has compared over 80 combinations of sites and cropping systems. This provides an opportunity to compare different crop sequences and the legacy effects of crop choice and management over several years in a cropping system on nutrition, disease, weeds and soil water.

This paper will focus on systems where the cropping sequence included crops aligned with the three themes listed below within the same period (2016-2019 and 2020-2022).

1. Winter – winter only crops with short summer fallows, planting occurring at 50% plant available moisture (PAW). Crops included wheat, chickpea, canola and field pea.
2. Sorghum – sequence containing winter crops (wheat) leading into sorghum with the opportunity of double-crop chickpea.
3. Cotton – cropping sequence focusing on a dryland cotton crop, with rotation crop dependant on available profile moisture. The cotton plant was activated when soil moisture reached 80% PAW to increase yield potential.

Soil moisture and N status were measured at all sites before and post every planted crop or twice annually during fallow years. Crops were managed and sown according to local best management guidelines. For example, relevant to our paper here, cotton was planted on single skip (2 in 1 out) configurations in the higher rainfall regions, and super single or double-skip in the western sites (e.g. Mungindi). Similarly, sorghum was sown on 1 m solid in the eastern sites, but on single skip in drier environments.

Across the systems, the inputs required in each system were recorded to calculate the system gross margin return using a 10-year average grain price to Brisbane port minus a set freight charge. Commodity prices per tonne included – wheat = $269, chickpea = $504, fababean = $382, sorghum = $220, cotton = $1090 (lint and seed), which equates to a cotton price of $490/bale and seed price of $260 per tonne.

Summer crop sequence performance

Using the farming systems data from Narrabri, Spring Ridge and Pampas we explored how crop sequences involving a summer pillar crop of sorghum or dryland cotton performed compared to a winter crop only system. This paper will focus on a 3-year period and 2-year period where common periods of comparison were possible between all research sites.

There is a contrast in weather conditions between the sites and the two periods of study. The first period (2015-2019) received lower than average rainfall across the sites (approximately 1600-1800 mm of rain over this period, or 400-450 mm per year), which induced longer fallow periods across all sequences, and several crops achieved low or negative gross margins owing to very little in-crop rainfall.

Nonetheless, these comparisons show the sequences involving a summer crop of sorghum were superior to the winter-only sequences at all 3 sites in terms of gross margin and system water-use efficiency (i.e. $/mm). Crop sequences targeting dryland cotton were variable, achieving lower GM returns at 2 sites (Narrabri and Pampas). The dryland cotton yields were reduced by hot and dry conditions, achieving yields of 2-2.5 bales per ha (Table 1). On the other hand, the crop sequence targeting dryland cotton at Spring Ridge, achieved a similar total gross margin from this single crop, despite being fallow the remainder of the time.

The winter-only sequence did not plant a crop in the 2018 winter at any of the sites due to lack of accumulated moisture and/or a lack of surface soil moisture to allow sowing.

Table 1. Performance and N balance of 3-year crop sequences (2016-2019) comparing the systems based on winter crops including break crops or using a sorghum or cotton crop at three farming systems experimental sites. The notation for the sequence of crops include: x = 6-8 month fallow, Cp = Chickpea, Wt = Wheat, Fp = field pea, Cn = Canola, Sg = Sorghum, Ct = Cotton.

Location	Pillar crop	Rotation	Grain yield (T/ha)	Total gross margin ($/ha)	N applied (kg/ha)	N exported (kg/ha)
Narrabri	Winter	x-Fp-x-Cn-x-x-x-Wt	2.7	-116	154	96
	Sorghum	x-Cp-x-Wt-x-x-Sg-x	5.7	1292	81	137
	Cotton	x-x-Ct-x-x-x-x-x	1.1	766	58	45
Spring Ridge	Winter	x-Fp-x-Wt-x-x-x-Cn	7.0	1057	57	200
	Sorghum	x-Cp-x-Wt-x-x-Sg-x	6.7	1487	86	173
	Cotton	x-x-x-x-Ct-x-x-x	2.1	1440	29	66
Pampas	Winter	x-Cp-x-Wt-x-x-x-x	6.7	2195	41	198
	Sorghum	x-x-Sg-Cp-x-x-Sg-x	13.2	2661	46	239
	Cotton	x-x-Ct-Wt-x-x-x-x	3.2	1776	151	37

The second period of this study occurred between 2020 and 2022. During this time, the research sites received above average rainfall, improving grain yield and crop gross margins. This study highlighted the gap between system productivity and system economics, as the sorghum system achieved high grain yields at both Narrabri and Spring Ridge, but resulted in the lowest system gross margin (note a planned chickpea crop for the 2022 winter after the sorghum may boost the sorghum system's crop returns). In contrast, the cotton system produced lower grain yield but the highest system GM, with $5111 per ha at Narrabri and $4539 per ha at Spring Ridge.

The system N use (change in mineral N plus applied N fertiliser) was similar between treatments at Narrabri, ranging from 202 to 235 kg N per ha over the cropping sequence, but Spring Ridge with the higher grain yields of both the winter and sorghum systems resulted in greater variance. The winter system had lower N use, as the fababean legume crop provided a significant portion of required N, reducing N fertiliser application by 130 kg N per ha to the cotton system and 290 kg N per ha to the sorghum system.

Table 2. Performance of 2-year crop sequences between 2020 and 2022 comparing systems containing a winter break, and a summer sequence containing either sorghum or cotton. The notation for the sequence of crops include: x = 6-8 month fallow, Cp = Chickpea, Wt = Wheat, Sg = Sorghum, Ct = Cotton.

Location	Pillar crop	Rotation	Grain yield (T/ha)	Total gross margin ($/ha)	System N use (kg N/ha)	Change in mineral N (kg N/ha)
Narrabri	Winter	x-Wt-x-Cp-x	6.5	2490	202	122
	Sorghum	x-Wt-x-x-Sg	8.1	1960	235	105
	Cotton	x-Wt-x-x-Co	7.9	5111	215	165
Spring Ridge	Winter	x-Wt-x-Fb-x	12.2	4196	110	80
	Sorghum	x-Wt-x-x-Sg	12.7	2810	300	140
	Cotton	x-Wt-x-x-Co	8.1	4539	240	120

Relative returns of summer crop options

The results from the three sites shows that it is crucial to consider the impact on profitability of the sequence of crops rather than individual crops grown in a particular season. When comparing the potential of sorghum and cotton as prospective summer crops, it is important to consider the future crop opportunities and legacies, particularly the opportunity to double crop following sorghum with chickpea which is rarely viable following cotton.

As such our farming systems sites have demonstrated a couple of examples of these two comparisons. Firstly, at Pampas in summer 16/17 both sorghum and cotton crops were sown following a long fallow, but a chickpea crop followed the sorghum crop in 2017. In this comparison, sorghum yielded 7.2 t/ha (GM of $1376) plus chickpeas produced a further 1.6 t/ha (GM of $573), for a total of $1950/ha, while the cotton crop yielded 1.9 t/ha (i.e., 3.8 bales/ha) for a GM of $1468.

The second comparison occurred during a lower yielding 2018/19 summer with grain yields significantly lower for sorghum (4.5 t/ha) with a net return of $710 per ha. There was no opportunity to double crop following the sorghum. By comparison, the cotton crop yielded (1.4 t/ha or 3.0 bales/ha), resulting in a net return of $1175 per ha.

Another example occurred during 2020-2022 at both the Spring Ridge and Narrabri sites where either a wheat-sorghum sequence or a wheat cotton sequence was studied. This study produced higher yields and gross margins than reported in 2018/19 ranging from 7.9 to 12.7 t/ha (Table 2). The higher yields during this study provided a base to compare these sequences in years with higher yield potential than the yields we observed during the 2016-19 phase. The key finding from this period was the impact of growing high value grains, as the cotton system at Narrabri had the highest system GM of $5111. This was more than double the GM of the sorghum and winter systems at Narrabri during the same period.

System water use

To evaluate the system legacy impact on water use, we evaluated WUE as the system GM divided by rainfall during the cropping sequence ($/mm). The indicator is a tool that values system returns per mm of rainfall.

The dataset from the project found systems containing cotton generated greater rainfall efficiency than both winter and sorghum systems when accumulated grain yield exceeded 5t/ha (Figure 1). Hence the cotton systems required less grain production compared to the other system to improve WUE. For example, for a cotton system to generate a WUE of $2/mm, it required 5.2t/ha, while the winter system required 8t/ha and the sorghum system required 13t/ha.

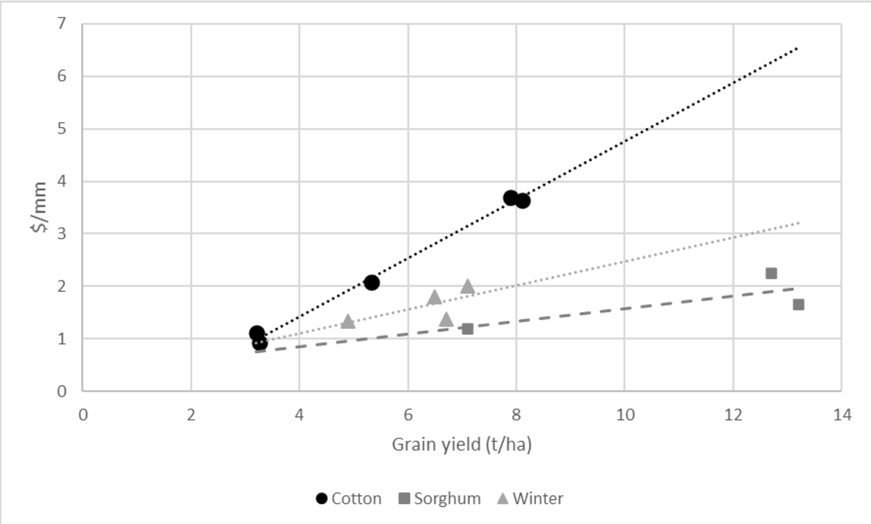

Figure 1. Crop water use efficiency (WUE as system gross margin by rainfall - $/mm) against cumulative system grain yield of three sequences based on winter only cropping, sorghum and cotton focused sequences at Narrabri, Spring Ridge and Pampas.

Water and N legacies of sorghum vs cotton

Further to the differences in system economic returns offered by different summer crop options, it is also important to understand and consider their legacies on soil water and nitrogen availability that can impact the performance and input requirements of subsequent crops.

Water use and harvest soil water

Several comparisons where both sorghum and dryland cotton were sown in the same season provide some comparisons of the legacy impacts on PAW and available N (Table 3). The data highlighted how low PAW after harvest restricted the potential for double cropping behind either sorghum or cotton. There was only one scenario (Pampas 2016/17) where sorghum was followed by a chickpea double crop. In the same season at Pampas, the cotton was followed by a salvage wheat crop, but there was a large difference in final soil water of over 100 mm. This difference persisted through a long fallow period, where a 60 mm difference in soil water was present at the sowing of the next crop.

The greater PAW after sorghum compared to cotton was also found at Pampas 2018/19, where post-crop PAW was ~0 mm after sorghum and negative 32mm after cotton. Similar levels of soil water extraction occurred at Mungindi (2016/17) and at both locations, the longer-term PAW was higher after sorghum compared to after cotton (range 5-35 mm).

We also note that cotton due to its lower biomass accumulation often left more residual N post-harvest than sorghum. The lower levels of mineral N after sorghum could have implications for N inputs required in subsequent crops

Table 3. Summer cropping impacts on plant available water (mm), water use efficiency (WUE) and residual mineral N

Site	Crop sequence	Pre-sowing PAW (mm)	Final PAW (mm)	Post short fallow PAW (mm)	Post long fallow PAW (mm)	Pre-sowing mineral N (kg N/ha	Final mineral N (kg N/ha)	Applied N fertiliser (kg N/ha)
Mungindi 2016	Sorghum	138	11		110	57	29	2
	Cotton	139	19		105	30	67	11
Pampas 2016/17	Sorghum-chickpea	240	100	155	130	195	55	5
	Cotton-wheat	253	0	80	70	178	100	76
Pampas 2018	Sorghum	120	2	70	150	114	94	34
	Cotton	149	-32	30	115	120	94	2

Note: short fallow = <6 months, Long fallow = >10 months.

Nitrogen use and residual N legacy

A key aspect of dominant summer rainfall areas is the beneficial N mineralisation from soil organic N occurring during the warmer months. The total amount of mineral N from organic sources in northern farming systems has been documented by Baird *et al*., (2018), where fallow periods, especially over the summer months, significantly increased mineral N within the system. Growing summer crops did reduce the mineral N accumulation during the warmer months, but applied fertiliser N was low (2-76 kg N/ha) as native N sources from the soil supplied a significant amount of N to the plant. The project found that the longer season growth of cotton had greater use of mineralised N and maintained soil mineral N levels compared to sorghum. As a result, residual N after cotton in all comparisons in Table 3 were greater than the residual N after sorghum crops (the difference ranging from 38-75 kg N/ha).

The legacy impact on rotation crops

The immediate returns of summer crops can be negated by the poor performance of the subsequent winter crop (Table 4). Firstly, when we compare a winter dominant cropping system (chickpea-fallow-wheat) to a summer-winter double crop (cotton-wheat or sorghum-wheat) situation at Narrabri, we demonstrate the significant yield penalty (60%) likely from the reduced soil water prior to planting the subsequent crop.

Second, the longer growing season of cotton had a greater influence on soil water use, decreasing the sowing PAW for the following crops and resulting in a significant reduction in yield compared to the crop grown following sorghum. Consequently, there is a high risk of crop underperformance when cropping after cotton, and generally growers will need to fallow their fields until the soil has been able to restore soil water levels to reduce the risk of lower crop yields.

Table 4. Legacy impact of summer crops on the subsequent crop yield

Site	Crop	Previous crop (season)	Following crop yield (t/ha)
Narrabri 2017	Wheat	Cotton (2016/17)	1.0
	Wheat	Chickpea (2016)	2.2
Pampas 2020	Sorghum	Cotton (2016/17)	2.8
	Sorghum	Sorghum (2016/17)	4.1
	Mungbean	Cotton (2016/17)	1.1
	Mungbean	Sorghum (2016/17)	1.3
Mungindi 2018	Wheat	Cotton (2016/17)	1.2
	Wheat	Chickpea (2016)	0.8

Measured disease and nematode levels

Summer crops provided a break for winter crop disease and nematode loads in our cropping soils. At Narrabri *P. thornei* root lesion nematode numbers were maintained at low levels after a cotton crop within the Low intensity system (Figure 2). At the same time, a winter-based sequence containing wheat and chickpea (Baseline), resulted in a spike for *P. thornei* (8.8 *Pt*/g soil). As a result of this spike in nematode numbers within the Baseline system, management was required to select wheat cultivars with higher nematode tolerance.

The use of summer crop options also reduced moderate to high levels of yellow leaf spot inoculum down to low concentrations at the Spring Ridge site. This break in disease and nematodes allows for a greater diversity of crop choices for future rotations, as the susceptible crops are unlikely to suffer yield loss from the lower pathogen loads in the cropping system (Erbacher, 2019).

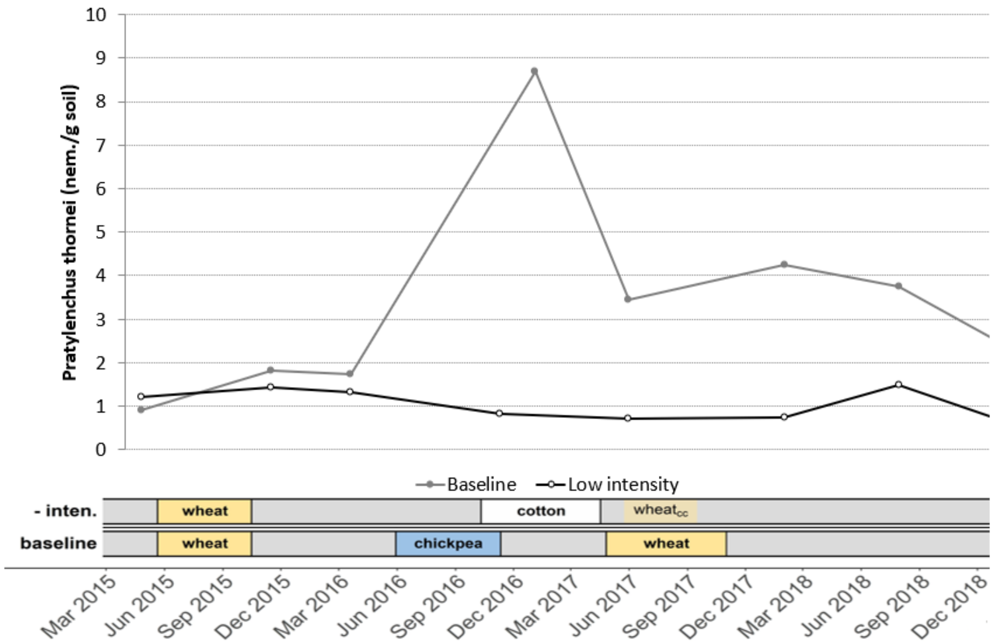

Figure 2. *P thornei* levels at Narrabri between 2015 and 2018. Baseline = Baseline, - inten. = Low intensity.

Conclusion

Summer crops provide a complementary addition to cropping systems in northern NSW and southern Queensland. The improvement in rainfall use efficiency due to the immediate use of summer rainfall, can provide growers with greater returns in terms of $/mm, as compared to waiting to plant a winter crop. Despite the risk of missing crops and the need to either long fallow or double crop in order to return to a winter crop sequence, even under the dry seasonal conditions between 2015-2019, sequences involving a summer crop have performed better. If rainfall does become limited late in the growing season and the harvest PAW is low, the opportunity for a winter double crop is low and significant yield penalties (up to 60%) are likely for such crops following a summer crop (especially cotton).

Reference

Baird J, Lonergan G and Bell L (2018). Investigating the impact of rain-fed cotton on grain production in northern farming systems. GRDC Grains Research Update

Erbacher A, Baird J, Whish J (2019). Investigating western farming systems. GRDC Grains Research Update

Bell L, Anderson B, Aisthorpe D, Verrell A, Baird J, Erbacher A, Gentry J and Lawrence D (2020). Summer crops: relative water use efficiencies and legacy impacts on farming systems. GRDC Grains Research Update

Erbacher A, Gentry J, Bell L, Lawrence D, Baird J, Dunn M, Aisthorpe D and Brooke G (2020) Nitrogen and water dynamics in farming systems – Multi year impact of crop sequences. GRDC update

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Jon Baird
NSW DPI
21888 Kamilaroi Highway, Narrabri
Ph: 0429 136 581
Email: jon.baird@dpi.nsw.gov.au

Summer crop choice in northern farming systems – impacts on root lesion nematode, charcoal rot, AMF and winter cereal crop pathogen levels

Steven Simpfendorfer[1], Lindsay Bell[2], Brook Anderson[2], Darren Aisthorpe[3], Mike Nowland[1], Jon Baird[1], Andrew Erbacher[3], Kathi Hertel[1], Greg Brooke[1]

[1] NSW Department of Primary Industries
[2] CSIRO Agriculture and Food
[3] Department of Agriculture and Fisheries, Queensland

Key words

pathogens, PREDICTA®B, disease risk, crop rotation, break crop, Fusarium crown rot

GRDC code

CSA00050, DAQ00192, DAQ2007-002RTX

Take home messages

- Summer crop choices are complex and should include consideration of their relative impact on pathogens and beneficial soil biota such as arbuscular mycorrhizae fungi (AMF)
- Mungbean resulted in the greatest increase in AMF populations but also elevated disease risk for charcoal rot and the root lesion nematode (*Pratylenchus thornei*) compared with sorghum, cotton, maize, sunflower and millet
- Summer crops generally reduced Fusarium crown rot risk for following winter cereal crops but variation appeared to exist in their relative effectiveness
- Maize, cotton, sorghum and mungbean appear to be potential alternate hosts for the winter cereal pathogen *Bipolaris sorokiniana* (common root rot), while sunflower does not appear to be a host
- Quantification of individual summer crop choices on pathogen levels has highlighted potential areas requiring further detailed investigation to improve management of these biotic constraints across northern farming systems.

Introduction

Crop choice decisions often involve trade-offs between different aspects of farming systems. In particular, crop choice should consider the need to maintain residue cover, soil water and nutrient availability, and managing pathogen inoculum loads using non-host crops to avoid or reduce risk of problematic diseases (e.g. Fusarium crown rot). This is increasingly challenging as many cropping systems face evolving diseases and weed threats. Hence, understanding how different crops impact on these aspects is critical.

With limited winter rotation crop options in the northern grains' region, summer crops offer advantages as break crops within cropping sequences. Incorporating a mix of summer and winter crops allows variation in herbicide and weed management options, often also serving as disease breaks within the system. For example, sorghum is known to be resistant to the root lesion nematode *Pratylenchus thornei* (*Pt*), allowing soil populations to decline. However, the increasing use of summer crops in many regions, has seen an increase in the frequency of other diseases (e.g. charcoal rot caused by the fungus *Macrophomina phaseolina*). Similarly, using long fallows to transition from summer to winter crop phases can induce low levels of beneficial arbuscular mycorrhizae fungi (AMF) populations associated with long-fallow disorder. In this paper, we interrogate the data collected from northern farming systems research sites over the past 6 years to examine how different summer crop options impact on levels of both pathogen and AMF populations within farming systems.

What was done?

Seven research sites were established in 2015 to test a range of different farming systems in different environments across northern NSW, southern and central Qld. Over the life of the project, the team has sampled and analysed soil (0-30 cm) using the PreDicta® B quantitative PCR (qPCR) DNA analysis to examine how pathogens and other soil biology have varied over a range of crop sequences. A specific PreDicta® B test panel targeted at quantifying a wide range of pathogens important to the northern grains region has been used throughout the project. Here we have looked specifically at the impact of summer crops grown in these crop sequences to calculate the extent of change in DNA populations of pathogens and AMF associated with crop choices. It should be noted that populations are what have naturally developed within each system at the various sites and were not artificially inoculated.

Data from site-crop combinations where a particular pathogen or AMF was not present or below testing detection limits was excluded, as this does not provide a useful indication of the propensity of a crop choice to impact a particular pathogen or AMF population. PreDicta®B data from soil samples collected at sowing and after harvest of each summer crop were used to calculate relative changes or multiplication factor for populations over their growing season for the various summer crop rotation options. This multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0) in pathogen levels following growth of different summer crops.

What did we find?

Root lesion nematodes

Root lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic plant parasites which feed on crop roots. Two important species are known to infect crops in eastern Australia, namely *Pratylenchus thornei* (*Pt*) and *P. neglectus* (*Pn*). *Pt* is known to be the more important species in higher clay content soils in northern NSW and Southern Qld while *Pn* is generally more prevalent in lighter soil types in south-eastern Australia. *Pn* generally feeds and causes root damage in the top 15 cm of soil whilst *Pt* can feed and damage roots down the entire soil profile. Root damage restricts water and nutrient uptake from the soil causing yield loss in intolerant winter cereal and chickpea varieties. Only *Pt* densities were prevalent at high enough densities across northern farming system sites to examine the effect of summer crop options on soil *Pt* populations.

Summer crops are known to vary in their susceptibility to *Pt* with sorghum, cotton, millet and sunflower considered moderately resistant-resistant (MR-R). Maize is considered susceptible-MR (S-MR) whilst mungbean is S-MRMS (GRDC root lesion nematode fact sheet - https://grdc.com.au/__data/assets/pdf_file/0031/385627/GRDC_FS_RootLeNematodesNorth_1902_13.pdf). The range in resistance ratings can relate to differences between varieties. Our results support these general findings. Mungbean resulted in the highest average increase in *Pt* populations, whilst sorghum favoured the lowest population increases (Table 1).

Table 1. Effect of summer crop choice on *Pratylenchus thornei* soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.4	8.3	3.2	2.0	3.4	5.0
Range	0.2 - 6.6	4.0 - 21.3	0.8 - 13.7	1.4 - 2.8	3.2 - 3.7	4.0 - 6.0
No. observations	31	20	10	5	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Charcoal rot (Macrophomina phaseolina)

Charcoal rot, caused by the fungus *Macrophomina phaseolina*, is primarily a disease of summer crops including sorghum, maize, cotton, mungbean and sunflower in northern NSW and Qld. Infection causes light brown lesions on crowns and roots and results in increased lodging and/or premature plant death when stress associated with dry weather occurs late in the growing season. *M. phaseolina* has a wide host range of more than 500 weed and crop species including winter cereals.

Table 2. Effect of summer crop choice on *Macrophomina phaseolina* (charcoal rot) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	9.5	150.0	20.8	7.2	28.9	3.9
Range	1 - 27	5 - 1191	1 - 117	4 - 11	6 - 50	2 - 6
No. observations	23	23	9	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

All six of the summer crops grown increased average *M. phaseolina* populations by between 3.9 to 150.0 times demonstrating the known wide host range of this fungal pathogen (Table 2). However, considerable differences were evident between the various summer crop options with mungbean elevating populations 5 to 40 times more than the other crops (Table 2).

Arbuscular mycorrhizae fungi (AMF)

AMF colonise roots of host plants and develop a hyphal network in soil which reputedly assists the plant to access phosphorus and zinc. Low levels of AMF have been associated with long fallow disorder in dependent summer (cotton, sunflower, mungbean and maize) and winter crops (linseed, chickpea and faba beans). Although wheat and barley are considered to be low and very low AMF dependent crops respectively, they are hosts and are generally recommended as crops to grow prior to sowing more AMF dependent crop species, in order to elevate AMF populations.

There are two PreDicta® B qPCR DNA assays for AMF with combined results from both assays presented. It is important to remember that in contrast to all the other pathogen assays outlined, AMF is a beneficial fungus, so higher multiplication factors are good within a farming system context.

Table 3. Effect of summer crop choice on arbuscular mycorrhizae fungi (AMF) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.5	26.8	10.7	5.7	12.0	7.2
Range	0.4 - 12.4	2.2 - 61.5	1.8 - 32.0	3.4 - 8.0	6.3 - 17.6	6.5 - 7.9
No. observations	41	22	10	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Mungbean resulted in the highest average increase in AMF populations, whilst sorghum was the lowest (Table 3). Interestingly, even though millet was grown as a short cover crop twice within these farming systems, it resulted in around a 7-fold increase in AMF populations. Hence, millet may be a good option for restoring ground cover over summer and AMF populations which both decline following extended dry conditions.

Fusarium crown rot (Fusarium spp.)

Two PreDicta® B qPCR DNA assays detect genetic variants of *Fusarium pseudograminearum* with a separate third combined test detecting *F. culmorum* or *F. graminearum*. All three *Fusarium* species cause basal infection of winter cereal stems resulting in Fusarium crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain filling. Fusarium crown rot has increased in northern farming systems with the adoption of conservation cropping practices which include the retention of standing winter cereal stubble. Yield impacts however are sometimes offset by the higher levels of plant available water often available to the plant during grain fill in such systems when compared to tilled systems. The *Fusarium* spp. which cause this disease can survive 3-4 years within winter cereal stubble depending on the rate of decomposition of these residues. Recent research from PhD student Toni Petronaitis has also highlighted that inoculum levels can increase during fallow and non-host crop periods, with saprophytic vertical growth of the pathogen inside standing stubble under wet conditions. Inoculum within standing winter cereal stubble can then potentially be redistributed across a paddock with shorter harvest heights of break crops such as chickpeas. Hence, changes in Fusarium crown rot DNA levels may not represent actual hosting of the pathogen, rather they potentially include inoculum dynamics associated with saprophytic growth and/or redistribution of winter cereal stubble inoculum during harvest. DNA data for all three tests were combined for this interpretation to provide an overall level of *Fusarium* spp. DNA.

Table 4. Effect of summer crop choice on *Fusarium* spp. (Fusarium crown rot) soil populations

	Sorghum	**Mungbean**	**Cotton**	**Maize**	**Sunflower**	**Millet**
Multiplication factor*	1.7	2.9	0.4	0.5	-	-
Range	0.03 - 10.3	0.4 - 9.7	0.1 - 1.0	0.2 - 0.8	-	-
No. observations	19	8	3	2	-	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Limited observations were available to support conclusions on the relative effect of summer crops on *Fusarium* spp. associated with Fusarium crown rot. However, cotton and maize appeared most effective at reducing inoculum loads (Table 4). Results were more variable with sorghum and mungbean, but both generally reduced or only moderately increased Fusarium crown rot inoculum levels. Inoculum dynamics associated with saprophytic growth of *Fusarium* spp., potential redistribution during harvest of summer and winter break crops and the role of grass weed hosts appears worthy of further investigation to improve management of this disease across farming systems.

Common root rot (Bipolaris sorokiniana)

Bipolaris primarily infects the sub-crown internode of winter cereal crops causing dark brown to black discolouration of this tissue referred to as the disease ‘common root rot’. Common root rot reduces the efficiency of the primary root system in susceptible wheat and barley varieties resulting in reduced tillering and general ill-thrift in infected crops. This disease has increased in prevalence across the northern region over the last decade with the increased adoption of earlier and deeper sowing of winter cereals which exacerbates infection. There is little information on the effect of summer crop options on *B. sorokiniana* levels within Australian farming systems. One international study from Pakistan determined that millet, sorghum, mungbean and maize were hosts of *B. sorokiniana*, whilst sunflowers were a non-host (Iftikhar et al. 2009). Similar research has not been conducted in Australia.

Table 5. Effect of summer crop choice on *Bipolaris sorokiniana* (common root rot) soil populations

	Sorghum	**Mungbean**	**Cotton**	**Maize**	**Sunflower**	**Millet**
Multiplication factor*	3.9	2.6	6.8	7.4	0.04	-
Range	0.5 - 9.6	0.3 - 9.3	0.3 - 12.0	na	na	-
No. observations	12	6	3	1	1	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Although limited observations were available to support conclusions on the relative effect of summer crops on *B. sorokiniana* populations, the data appears to support the only previous study of host range from Pakistan (Iftikhar et al. 2009). Mungbean, sorghum and maize appeared to generally increase populations, whilst sunflower considerably decreased levels of this pathogen (Table 5). Cotton, which was not included in the Pakistan study, also appears to generally increase *B.*

sorokiniana soil populations (Table 5). These results indicate that the role of summer crops need to be considered when managing common root rot in northern farming systems. Further research is required to confirm the relative host range of this increasingly important pathogen.

What does it all mean?

Summer crop choice remains a complex balancing act but this research has highlighted some of the impacts on pathogen and AMF populations. For example, mungbean had the largest increase in beneficial AMF levels but had the negatives of elevating charcoal rot and *Pt* risk compared with the other summer crop options examined. Mungbean also did not appear to be as effective at reducing Fusarium crown rot risk for subsequent winter cereal crops compared with other summer crop options where data was available. The underlying reasons behind these apparent differences requires further investigation of Fusarium crown rot inoculum dynamics with a farming systems context.

These northern farming systems experiments have further highlighted the potential differential role of summer crop species as alternate hosts of the common root rot pathogen *Bipolaris sorokiniana*, supporting an overseas study. The use of qPCR within these experiments is unique in that it allows the relative changes in pathogen or AMF levels associated with various summer and/or winter crop choices to be quantified. This is more valuable than simple presence/absence data, in that it allows growers and their advisers to understand and manage potential changes in disease risk within their paddocks to limit impacts on profitability.

References

Iftikar S, Asad S, Munir A, Sultan A and Ahmad, I. (2009). Hosts of *Bipolaris sorokiniana*, the major pathogen of spot blotch of wheat in Pakistan. *Pak. J. Bot.* 41: 1433-1436.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We would also specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

Contact details

Steven Simpfendorfer
NSW DPI
4 Marsden Park Rd, Tamworth NSW 2340
Ph: 0439 581 672
Email: steven.simpfendorfer@dpi.nsw.gov.au

Lindsay Bell
CSIRO
203 Tor St, Toowoomba QLD 4350
Ph: 0409 881 988
Email: Lindsay.Bell@csiro.au

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How soil organic matter and carbon work!
Data from 500 paired-site comparisons across the northern region

David Lawrence[1], Michael Bell[2], Jayne Gentry[1], Suzette Argent[1], Rod O'Connor[1]

[1] DAF Qld, Toowoomba
[2] University of Queensland

Key words

soil organic matter, soil carbon, fertility decline, soil health, sequestration

GRDC codes

DAQ00182, DAQ00163

Take home messages

- Soil organic matter and its nutrients currently have far more value than soil carbon itself. Soil organic matter is 58-60% carbon, so soil organic carbon is used as an indicator of soil organic matter levels
- Soil organic matter (and carbon) levels are just a balance between the dry matter produced and retained in the paddock versus its subsequent loss and breakdown by microbes
- Grain production can reduce soil organic matter levels by up to 70%, mainly due to fallowing
- In-crop agronomy has much less effect on soil organic matter levels than land use changes, such as clearing land for cropping. However, modern farming practices that maximise water-use-efficiency for extra dry matter production are key to protecting soil organic matter. More crops with higher yields, pasture rotations and not burning or baling, will all help maintain soil organic matter levels
- Well-grown pastures can make major improvements in old croplands. Soil organic carbon levels under pastures have been measured at up to 1.0 t/ha/year higher than with continued cropping
- All grain growers need an informed soil organic matter strategy because it underpins their soil's resilience, nutrient supply, and general soil health.

Background

Soil organic matter is critical for healthy soils and sustainable agricultural production. This is not 'news' to growers, agronomists, or indeed anyone with a vegetable garden or compost heap at home. We know that healthy soils with high organic matter levels grow better crops that are easier to manage. However, we also know that soil organic matter (SOM) and soil organic carbon (SOC) levels are declining, which means continued grain production and healthy crops are needing more fertiliser, especially for nitrogen (N).

To make sensible decisions on how best to manage SOM and SOC on our own farms, we need to understand how SOM and SOC work, why their levels are declining, the implications for enduring profitability, and what we can realistically do about it.

Soil organic carbon – an indicator of soil organic matter

SOM is what's important to agricultural production. However, SOC is a reliable indicator (~ 58-60% of organic matter) that we can measure and so talk about. This means a soil with 1.0% SOC has ~1.7% organic matter by weight. Over time SOC has become a key indicator of soil health, the sustainability of long-term crop production and the need for continual inputs to maintain productivity.

Forms and dynamics of soil organic matter and carbon

SOM is 'everything in or on the soil that is of biological origin, whether it's alive or dead'. It includes live plant roots and litter (not shoots), humus, charcoal, and other recalcitrant residues of organic matter decomposition. It also includes the organisms that live in the soil that are collectively called the soil biota (e.g., fungi, bacteria, mites, earthworms, ants and centipedes). The one thing all these materials have in common is that they all contain carbon.

Ultimately, SOM is derived from decomposing plant material as the soil biota feed on it for energy and nutrients. Populations in the biota all wax and wane with the supply of their preferred foods and predation by other organisms. Similarly, the amount and age of different SOM/SOC 'fractions' will fluctuate in response to the quality and quantity of inputs (i.e. residue type and frequency of addition) and the influence of moisture and temperature on the decomposing organisms (Figure 1).

Microbial respiration during decomposition releases carbon dioxide (or methane in some conditions) and any nutrients surplus to the biota's needs are released (mineralised) in inorganic forms for use by other microbes and plants. However, soils are generally nutrient-poor environments so as the decomposition process occurs and the organic materials age in the soil, there is generally more carbon (C) released as CO_2 than there are surplus nutrients released. For example, fungi need a C:N ratio of ~8:1 (8 C atoms for every N atom) available to grow more hyphal threads, but can digest poor quality crop residue with C:N ratios up to ~100:1. As a result, surplus C is respired while the N is conserved, and the soil organic materials become increasingly nutrient rich as it ages. This enrichment of nutrients in humus and more recalcitrant/charcoal-like materials occurs especially with N and sulphur (S). The humus that eventually forms from decomposition of, say, cereal straw will have C:N ratios of approximately 12:1, rather than the 100:1 in its original form. The lower the C:N ratio of the material being decomposed (i.e., humus versus fresh cereal straw) the more likely there is to be net release of mineral N. After so many cycles of digestion and excretion, these humic materials are less readily decomposed than the initial plant residues, but the nutrients they contain ensure that they remain a valuable source of nutrients contributing to soil fertility.

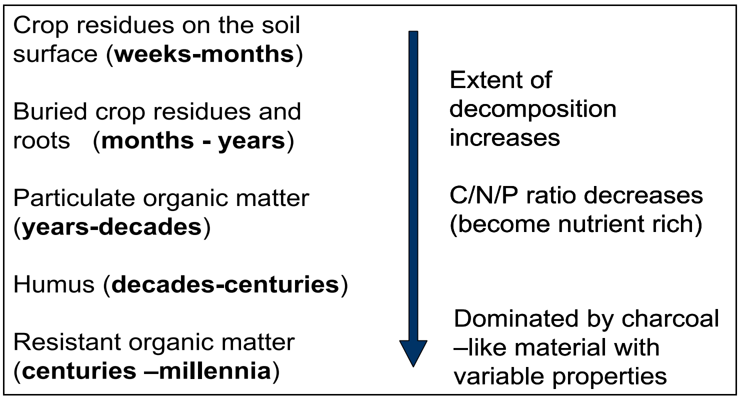

Figure 1. Forms of soil organic matter and carbon and their indicative 'half-life' in the soil, which also indicates how long the next decomposition stage takes to form.

Benefits of soil organic matter

While SOM contains ~60% organic carbon, it is the decomposition of organic matter with its associated materials that drives most physical, chemical, and biological soil processes, supplying a range of nutrients needed by both plants and soil biota. Organic matter helps major soil functions:

(i) Physically with better structure, infiltration, and water holding capacity,

(ii) Chemically with better nutrient supplies and pH; and

(iii) Biologically by maintaining a food supply for microbes and the microbial activity that supplies available nutrients for plants and competes with pathogens.

However, the impact of these functions varies with different soils and the types, or fractions, of SOC that we measure (Figure 2). The width of the lines represents the impact of soil carbon on that function, and the colour represents the fraction of the carbon that provides that function in the soil. For example, the relative contribution of organic matter/carbon to cation exchange capacity (CEC) and water holding capacity is large on sandy soils but small on heavy clays that already have high CECs and water holding capacities. Similarly, the bulk of nutrients come from the humus fraction, while the particulate fraction provides much of the energy for microbial activity.

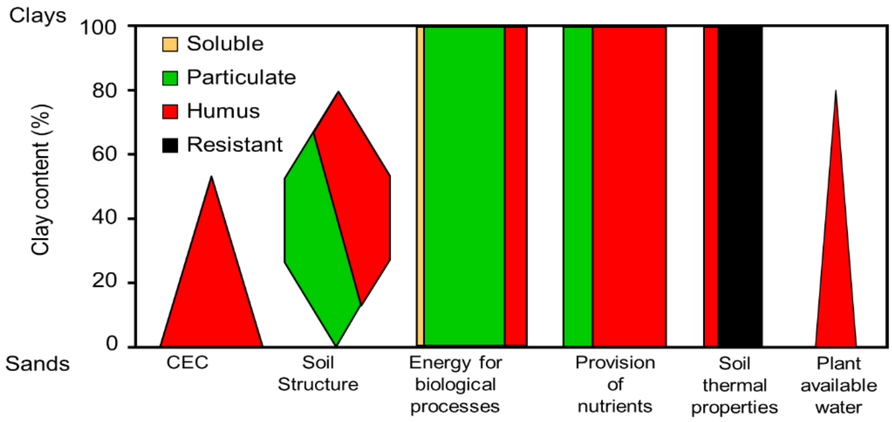

Figure 2. The impact of soil organic carbon fractions and clay content on soil function (Hoyle et al. 2006).

What is soil organic matter really worth to grain producers?

The direct economic value is hard to quantify for many of the soil functions that organic matter supports. Yet, it's clearly higher than the value of soil carbon alone; 1 tonne of SOC is associated with ~100 kg organic nitrogen, so when the SOC levels in the 0-10cm layer of a brigalow/belah soil decline by 1% (10-13t/ha), it means up to $1500/ha of nitrogen has been released for crops to grow on and which is no longer present in that soil. For all nutrients, including phosphorus and sulphur, this figure may be as high as $2000/ha.

These nutrients may not have been wasted as the decomposing natural organic matter reserves enabled cropping for 30+ years with little or no fertiliser. However, fertiliser use is now increasing as the supply of nitrogen and other nutrients from SOM decline, and the soils' reserves of mineral nutrients such as phosphorus and potassium are also depleted. Profitability of production will clearly change as we need to replace more nutrients in older cropping soils.

Soil organic matter & carbon levels

Natural organic matter levels vary with each location's soil type, rainfall and vegetation. The SOC levels for each farming system then results from its balance between inputs (e.g., plant residues other organic inputs) and losses (e.g., erosion, decomposition, harvested material) (Figure 3).

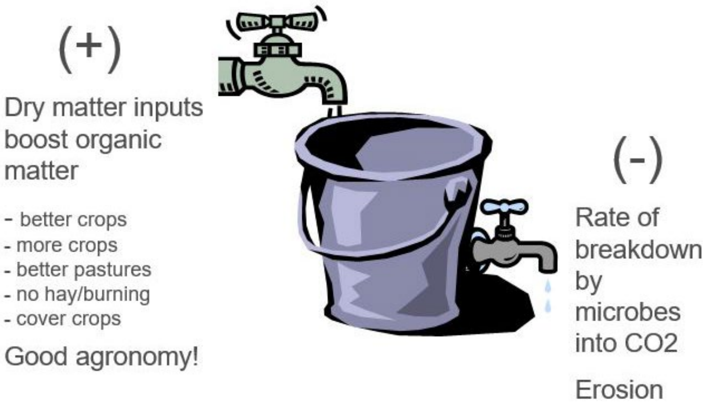

Figure 3. Soil organic carbon levels: a balance between dry matter (organic) inputs, losses and decomposition.

Soil organic carbon levels in the northern region

Data from 500 paired-site comparisons from 2008-2017 show the effects of land-use and farming practices on SOC levels across the northern grain region. Total Organic Carbon in the top 10 cm of the soil (TOC $_{0\text{-}10\ cm}$) under remnant vegetation at selected sites varied from 0.7 at Walgett to 3.8-5.0% on brigalow soils at Condamine and Central Queensland (Figures 4 and 5). Critical levels for each soil/location are not defined because the varied functions of organic matter are difficult to match with crop productivity. Basically, more organic matter is better.

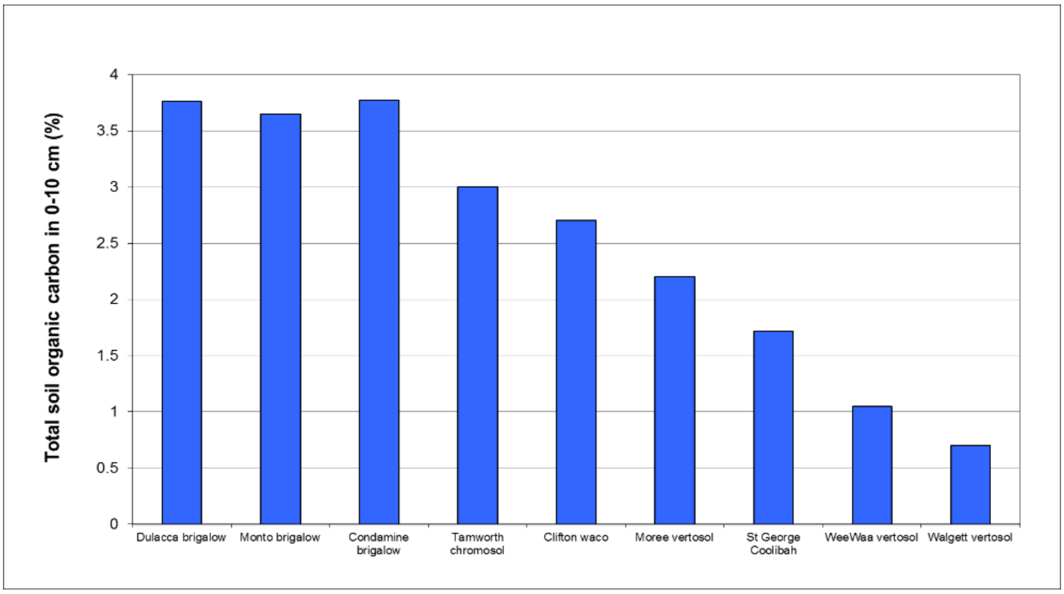

Figure 4. The impact of location/land type of soil organic carbon levels (0-10 cm) under remnant vegetation.

Declines in soil organic carbon under cropping

The most consistent land-use impact on SOC was the decline when country was cleared for long-term cultivation (Figure 5). There was a clear and dramatic impact of clearing and cultivating for 20+ years. These reductions in Total Organic Carbon (TOC) were most dramatic on the highly fertile brigalow soils in Queensland. Declines of 60-70% (i.e., >2-3% TOC) were common, representing declines in the natural nutrient capital to a depth of 30cm in these soils of up to $5000-8000/ha.

This decline under cropping is driven by fallowing to store moisture. Fallow efficiencies typically range between 20-30%, which means 70-80% of fallow rainfall is lost, mostly to evaporation. It is not transpired by plants to grow more dry matter and replenish the organic matter that continues to be decomposed by microbes in the moist soil.

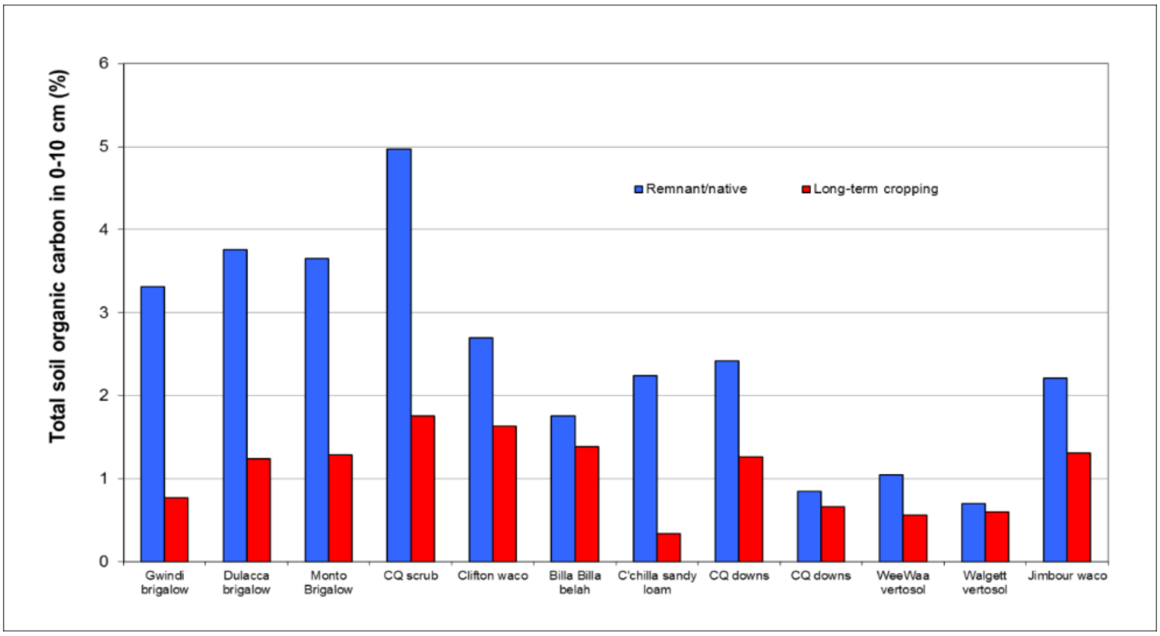

Figure 5. The impact of long-term cropping (20+ years) on soil organic carbon ($TOC_{0\text{-}10\ cm}$).

Pasture development also reduced SOC levels, confirming that the native vegetation (typically with trees/shrubs) produced more dry matter than cleared pastures, even if it's not valuable as feed. The declines under pastures were less dramatic than cropping. Pastures do not have fallows and use most of their rainfall to grow dry matter that's ultimately returned to the soil. The higher productivity of sown pastures produced higher SOC levels than native pastures in nearly all cases.

Rebuilding soil organic carbon levels with pastures

When compared to paddocks under continuous cropping, SOC levels were higher in most paddocks that had been returned to pastures for at least five years, both in the more marginal Western Downs districts (Figure 6) and the higher rainfall Darling Downs. In isolated cases the pasture paddock had a lower soil carbon level; in each case, it was confirmed that those paddocks were returned to pasture because they were not performing in the first instance (due to some confounding influence).

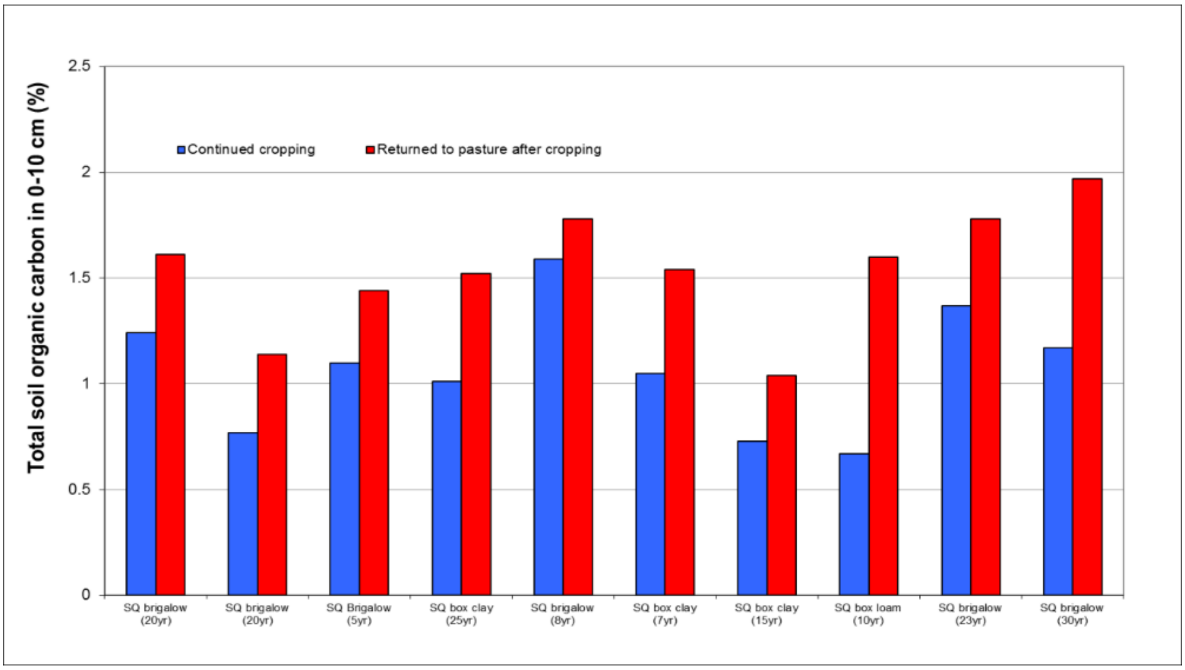

Figure 6. Total organic carbon comparisons for croplands resown to pasture (Western Downs).

The changes in carbon stocks showed that the difference between the paddocks that continued to be cropped and those resown to pastures could be at least 1.0t/ha/yr in well-grown pastures (Table 1). However, some pastures provided little if any increase in soil carbon stocks after many years. The determining factor appears to be the presence of legumes in the better performing pastures and their absence in the poorer performing paddocks.

Three-way comparisons between remnant vegetation, long-term cropping and long-term cropping land returned to pastures, also revealed the variable ability of pastures to build or maintain soil carbon levels (Figure 7). Re-investigation of the soil test data suggests the recovery in soil carbon at the sites reflects the soils' phosphorus levels and the subsequent legume growth in the pastures:

- The best performing pasture for rebuilding soil carbon stocks (Roma), had high phosphorus levels and strong legume (medic) growth which may supply an extra 30kg N/ha/yr and produce 900-1200 kg extra dry matter each year for better productivity and higher soil carbon stocks.
- In contrast, the pasture with no carbon impact (Condamine), was extremely deficient in phosphorus (3mg/kg Bicarbonate $P_{0\text{-}10cm}$) and had no legume growth. This left the pasture with little dry matter production due to extreme N deficiency after a cropping phase. This pasture may never recover without remedial action and the farmer may have low dry matter levels, poor beef production and little increase in soil carbon stocks for the foreseeable future.

This insight on the importance of soil phosphorus had a major impact on the participants in the projects. It was the catalyst for many of the mixed farmers developing strategies to maintain soil phosphorus levels on their cropping country for bigger and better crops and yields and to maintain the flexibility to use pastures to rebuild soil carbon and soil health levels into the future if need be.

Table 1. Examples of the change in carbon stocks when cropland was returned to pastures.

Location	Soil/vegetation	Time in Crop (years)	Time in Pasture (years)	Carbon stocks (t/ha)	Δ Carbon (t/ha/yr)
Samples to 30cm (0-10cm + 10-30cm) using conservative bulk densities of 0-10: 1.25 & 10-30: 1.3					
McCallister	Waco clay	60 50	0 10 (native grass)	44 54	+1 t/ha/yr
Jandowae	Brigalow clay	40+ (baled) 40+	0 40 (sown grass)	49 63	+0.4 t/ha/yr
Nindigully	Red box loam	40 30	0 10 (sown grass)	28 31	+0.3 t/ha/yr
Nindigully	Coolibah clay	25-30 25-30	0 10 (sown grass)	17 21	+0.4 t/ha/yr
Samples to 10cm only using conservative bulk densities of 0-10: 1.25					
Warra	Brigalow clay	45 35	0 10 (sown grass/medic)	12 17	+0.5 t/ha/yr
Glenmorgan	Box wilga loam	25 15	0 10 (sown grass/medic)	8 20	+1.2 t/ha/yr
Condamine	Brigalow belah clay	40 30	0 10 (sown grass/medic)	15 25	+1 t/ha/yr
Talwood	Red clay	40 40	0 7 (sown grass/medic)	13 19	+0.9 t/ha/yr
Talwood	Brigalow clay	15 15	0 3 (sown grass)	14 18	+1.3 t/ha/yr
Talwood	Grey Clay	25 15	0 10 (sown grass)	9 13	+0.4 t/ha/yr
Goondiwindi	Brigalow belah clay	30 30	0 20 (sown grass)	16 20	+0.2 t/ha/yr
Condamine	Belah wilga clay	35 20	0 15 (native grass)	12 12	+0 t/ha/yr

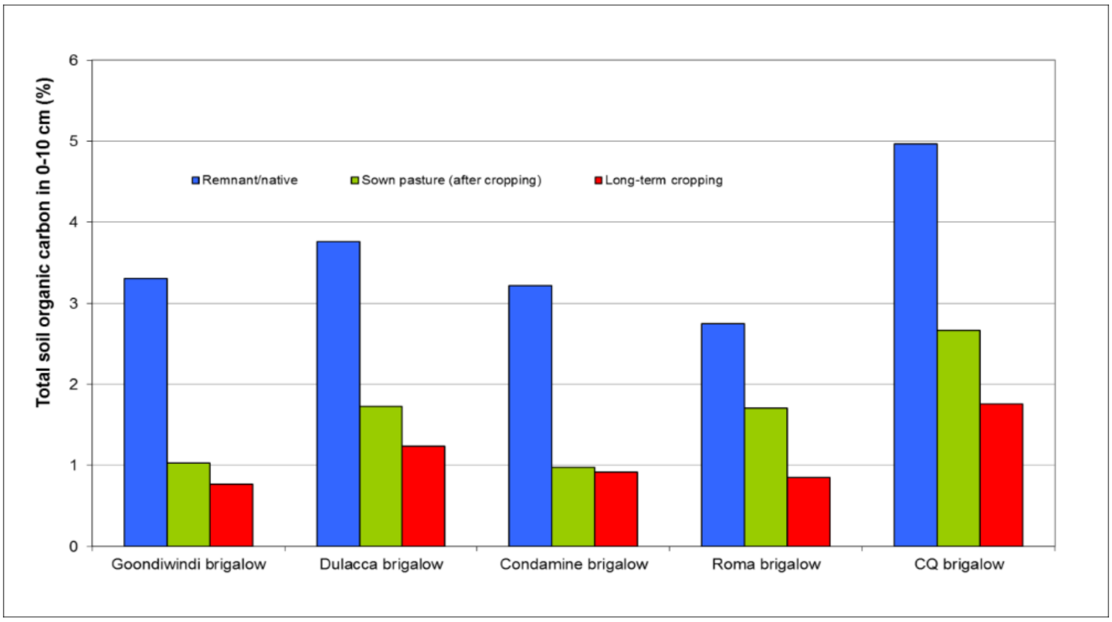

Figure 7. Three-way comparisons of the soil carbon impacts of cropping and resowing pastures.

A final consideration for growers that do use pasture phases to rebuild their SOM and SOC levels is how long it takes for more stable forms such as humus to develop? The half-life of particulate carbon indicates that humus takes 'years to decades' to form (Figure 1). This means a 5-to-10-year pasture phase will primarily increase the more easily decomposed (labile) particulate carbon with much less nutrient rich humus than the remnant vegetation had over centuries. The rebuilt SOM and SOC levels will break down much faster when returned to cropping than when the country was initially developed (Figure 8) and will require careful management with high productivity to maintain.

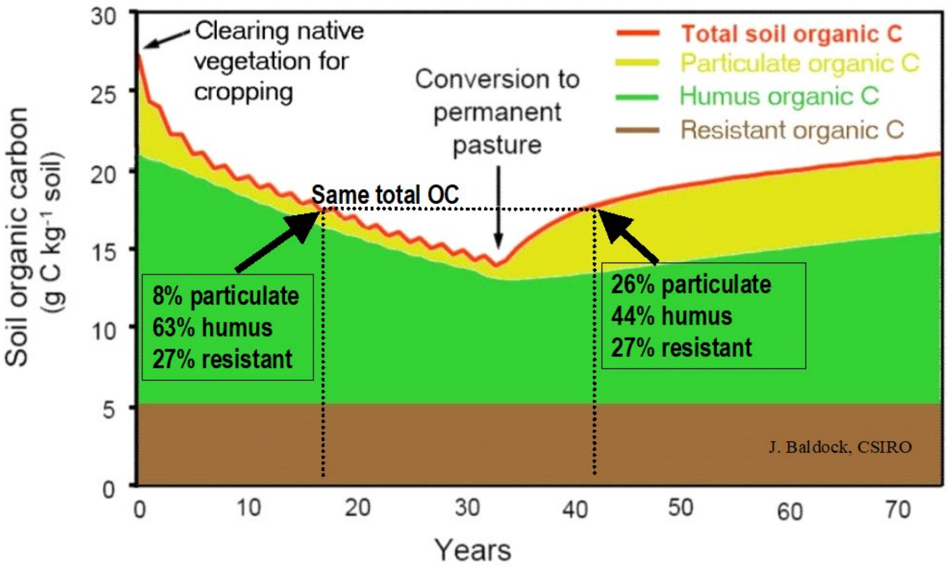

Figure 8. An illustration of changes in the soil organic carbon fractions under development for cropping and a subsequent return to pastures Hoyle et al 2006)

Rebuilding soil organic carbon levels in crop soils

While mixed farmers may be able to use pasture phases to manage their soil carbon levels, most grain farmers were interested in options for their permanent cropping paddocks. A range of agronomic practices were assessed in the paired-site comparisons for their impacts on SOC. The impacts of these different agronomic practices were minor at best and appeared to be overwhelmed by the effect of fallowing:

- Crop choice: Crops with different levels of dry matter (e.g., cotton vs grain) showed minor differences, reinforcing the overall impact of a prolonged fallow in northern farming systems. This re-assured some cotton growers who worried that cotton farming systems were further degrading their soils. Systems with increased use of legumes also had no clear impact on SOC.
- Forage crops: Forages have potential to produce more dry matter and maintain higher SOC levels than grain crops (Figure 9). However, the differences were minor at best, perhaps because many forage crops under-perform on poorer soils with less management and fertilisers and stock redistribute some residues via manure around watering points and shade lines.
- Manures: It is logical for grain-only producers to think that manures add dry matter and must at some level increase SOC. However, the SOC levels showed no real benefit from the relatively low commercially used rates (typically to supply phosphorus) and the rapid breakdown of their labile carbon in manures (Figure 10). No comparisons of repeated use of heavy manure rates were available on crop land, as farmers with feedlots spread manure on all their cropping paddocks. In

some cases, SOC levels declined where manures and other biological products were used, perhaps due to people reducing the overall amount of nutrients being added. The key insight was to ensure that crop nutrient needs are met, and that compost teas and other products alone are not going to overcome nutrient deficiencies.

- Best modern practices: Modern farming systems with zero/reduced tillage and high nutrient replacement rates were compared to more traditional management practices. As farmers tend to change practices such as use of tillage and nutritional strategy across their whole farm, the project was unable to locate separate comparisons of different tillage practices and of high nutrient applications on paired paddocks. The data suggests potential for a small impact of modern practices on maintaining SOC levels, which requires further monitoring to confirm (Figure 11).

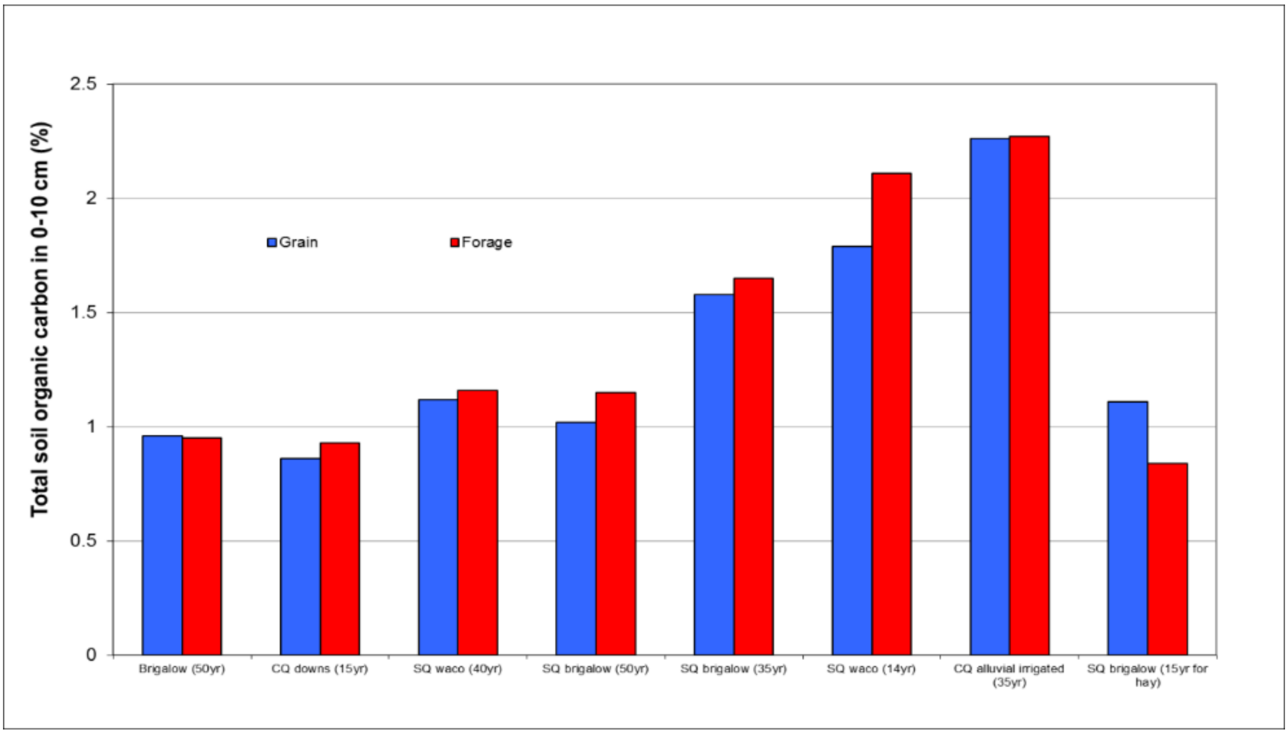

Figure 9. Total organic carbon levels under long-term grain and forage cropping.

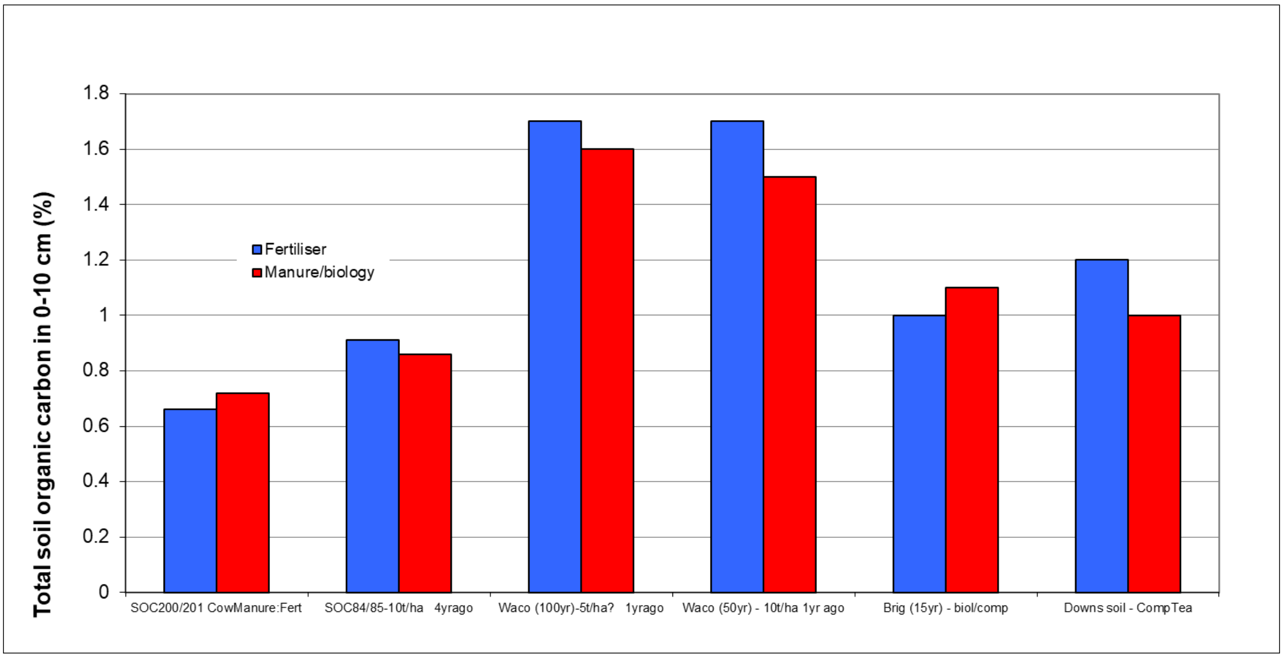

Figure 10. Total organic carbon levels under traditional fertiliser and manure/biological systems.

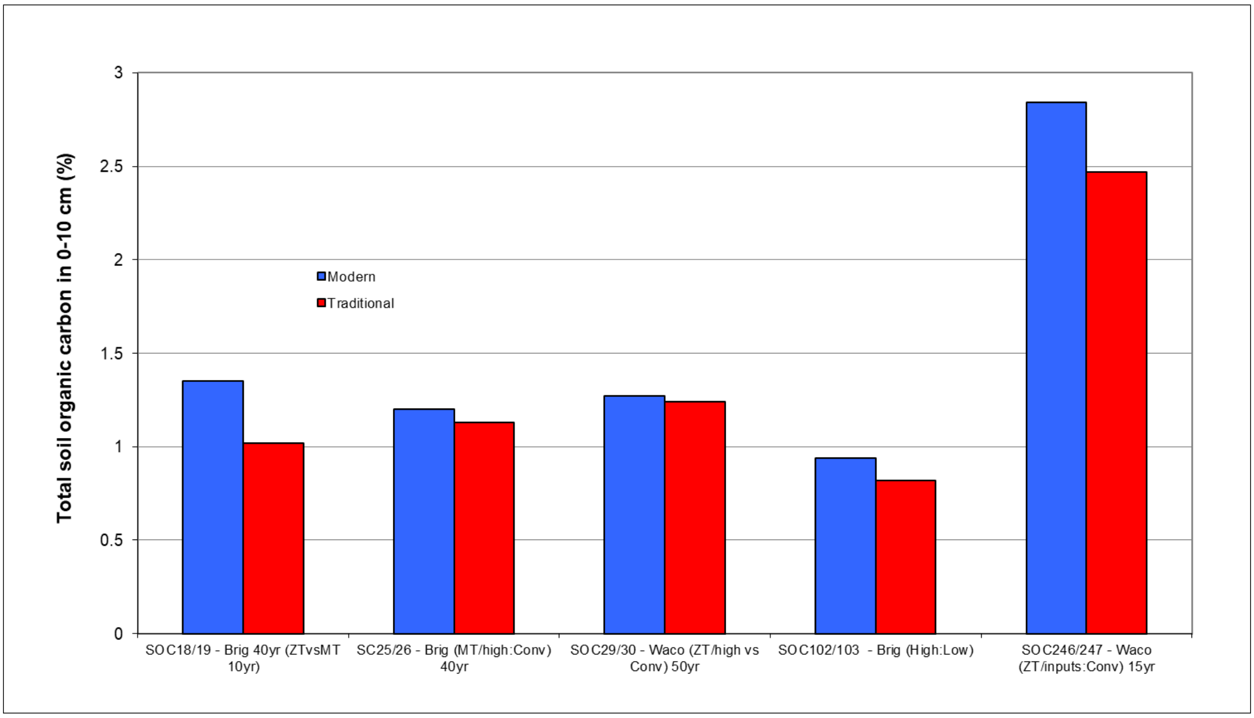

Figure 11. Total organic carbon levels under modern (less tillage, more fertiliser) systems compared to more traditional systems.

Implications

Long-term grain production clearly reduces soil organic carbon (and hence organic matter) levels. On well-structured soil this decline and the subsequent loss of soil nutrients such as nitrogen, may be managed by increased rates of fertiliser. However, management will need to be 'spot-on' as the soil will become less resilient and less able to respond to seasonal changes. These soils will also be more prone to disease, so again, good agronomy and timely management will become increasingly important.

For grain-only producers, strategies to maintain soil organic carbon will need to focus on using the best possible agronomy to grow the best crops, with as much dry matter as possible, as often as possible; balanced with the need for each crop to be profitable. Cover crops and companion cropping that seek to produce more on the same land by making greater use of rain may also offer some small improvements in soil organic matter and carbon.

Mixed farmers who have the option of prolonged pasture phases, have much greater potential to rebuild and manage their soil organic matter and carbon levels than grain-only farmers. The best results for rebuilding soil organic matter and carbon will be from growing the best, most productive, and profitable pastures for livestock. Positive results will require both a good supply of nitrogen from fertiliser and/or legumes with an adequate phosphorus supply for good legume growth to support high levels of pasture dry matter production.

Ultimately, any practice that increases the return of dry matter from stubble and roots will help maintain, or at the very least, slow the decline of soil organic matter and carbon levels in our cropping lands. This includes using zero/reduced tillage to maximise water capture and grow more crops and better higher yielding crops with adequate nutrition to meet their full potential; considering cover crops and companion crops if they can increase dry matter production without compromising grain yields; avoiding burning and baling that removes dry matter and nutrients from the paddock; and using pasture phases where practical. Introducing the best 'profitable' practices as soon as possible, not waiting until soils suffer major declines will be important, both in younger country and to prolong the gains after pasture phases that are used to rebuild SOM and SOC.

References

Hoyle, FC, Baldock, JA & Murphy, DV (2011) Soil Organic Carbon – Role in Rainfed Farming Systems In, P. Tow et al. (eds.), Rainfed Farming Systems, Springer

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the past financial support of the GRDC, Land & Water Australia and the Australian Department of Agriculture, Water, and the Environment; the authors would like to thank them for their continued support.

Contact details

David Lawrence
Queensland Department of Agriculture & Fisheries
PO Box 102 (203 Tor Street), Toowoomba, 4350
Ph: 0429 001 759
Email: david.lawrence@daf.qld.gov.au

Building soil carbon for your business

Peter Grace[1], Richard Eckard[2] and Warwick Badgery[3]

[1] School of Biology & Environmental Science, Queensland University of Technology
[2] Department of Agriculture and Food, The University of Melbourne
[3] NSW Department of Primary Industries

Keywords

carbon sequestration, soil carbon, soil organic matter.

Take home messages

- Many growers are already employing soil sequestration practices as the norm, but only additional activities are valid for claiming a carbon offset
- Soil carbon sequestration in grains systems is low unless a pasture phase is included
- When estimating carbon credits all greenhouse gases must be included i.e. soil carbon sequestration is potentially negated by nitrous oxide and other emissions
- The long term benefits of increasing soil organic matter for soil health are more profitable and low risk compared to the soil carbon market.

Introduction

Soil organic matter is the backbone of any sustainable farming system. In recent times, there has been significant interest in the role that soils can play in helping Australia meet its greenhouse gas reduction targets. Under the federal government's Australian Emissions Reduction Fund (ERF) which financially rewards carbon offsets, there are two legislated methods which involve soil organic matter or more specifically increases in soil organic carbon. These procedures are very specific and require detailed certified measurements of soil organic carbon and bulk density over nominated time periods. A number of international voluntary soil carbon methods also exist, but their validity as offsets in Australia may be questionable.

To engage in these soil carbon offset markets, farmers must first be able to demonstrate they are undertaking management activities which are in addition to their normal practice. For example, a farmer who changes to zero till practices will be rewarded if they have registered the field (i.e. defined a Carbon Estimation Area) and can show a measurable change in soil organic carbon in the top 30 cm or deeper. A farmer who has employed zero till for many years is unlikely to be rewarded unless there is some additional modification to this practice.

Unfortunately, placing a price on soil carbon has skewed the discussion away from what really matters to farmers, which is soil health and productivity. Soil organic matter, of which only half (~58%) is soil organic carbon has multiple benefits, most notably, maintaining nutrient supply and soil structure. Soil organic carbon is usually only about 1 to 5% of the total soil mass, with the higher concentrations normally under long-term grasslands or crop rotations with significant pasture phases.

What is soil organic carbon?

There is some confusion about what constitutes soil organic carbon. Plant residues on the soil surface, roots and buried plant residues (>2 mm) are not accounted for as soil organic carbon. These first need to be broken down into smaller fractions and decomposed to be considered soil organic carbon, which is why the soils are first sieved to two millimetres before an analysis, to remove all larger fractions. Gravel content and inorganic carbon (or carbonates in alkaline soils) must also be taken into account when accurately quantifying soil organic carbon.

Fractions considered to be part of the soil organic carbon (as per a soil analysis) would be Particulate Organic Carbon (POC; 2.0 – 0.05 mm) or labile C, Humus (<0.05 mm) or stable C, with Resistant Organic Carbon (ROC) being historic charcoal from fires or burning of stubbles. In other words, we must not confuse roots with soil organic carbon.

For sustained productivity, increasing the relative amount of POC is beneficial as this is readily decomposable and a supply of nutrients. To have confidence to sell soil carbon, you want a significant amount of carbon in a more recalcitrant (slowly decomposing) form i.e. stable, so that you have confidence that it will still be there in 25 to 100 years. These permanence time frames are required to engage in carbon markets.

Building soil organic matter

The inherent benefits and the role of soil organic matter for productive and profitable agriculture are well documented (Table 1).

Table 1: Biological, physical and chemical co-benefits that high soil organic matter may confer to an agricultural production system.

Biological roles	Physical roles	Chemical roles
- Reservoir of nutrients - Biochemical energy - Increased resilience - Biodiversity	- Water retention - Structural stability - Thermal properties - Erosion	- Cation exchange - pH buffering - Complex cations

(Source: Jeff Baldock)

Building soil organic carbon is basically an input-output equation; the inputs are crop and pasture residues and roots. The outputs are CO_2 from microbes which are actively decomposing and transforming the carbon fractions, using them as energy but in the process releasing nutrients back to the soil to support plant growth. As much as 90% of the carbon input is lost as CO_2. Soils with a higher clay content have a greater capacity to store carbon per unit of inputs. In a good rainfall year, the inputs increase in response to plant growth with a subsequent increase in outputs and an accumulation of carbon. Carbon inputs exceed outputs. In a drought, carbon inputs drop dramatically in response to reduced plant growth, but the outputs remain because the microbes respond to episodic wetting events and soil carbon decreases. Carbon outputs exceed inputs. Fallow years are good example of significant losses in soil carbon.

In Australia, rainfall determines the majority of soil carbon change in a stable management system (see Meyer *et al.,* 2015). Unless there is a significant change in management, e.g. moving out of conventional cultivation into permanent pasture in a high rainfall zone, the majority of the annual change in soil carbon is a function of rainfall, biomass production and its decomposition. Change in soil carbon in mixed cropping system can often be large and unpredictable, particularly from labile, relatively decomposable carbon (Badgery *et al.,* 2020).

Australia has over 20% more rainfall variability than most countries in the world (Love 2005). Banking on selling soil carbon and its permanence is therefore high risk given the frequency of drought. For example, Badgery *et al.,* (2020) reported that after 12 years of increases in soil carbon, this was reversed in the following 3 years in less than favourable climatic conditions.

In contrast, recent research has demonstrated that just two of the co-benefits of high soil organic matter (i.e. nitrogen mineralisation and water retention) confers as much as $150 per hectare per year productivity value in a pasture system in western Victoria, when the carbon trading value under the same scenario is less than $20 per tonne per hectare year (Meyer *et al.,* 2015). This raises the question, should farmers focus on trading soil carbon, or just bank the inherent productivity benefit of having higher soil organic matter, as there is no paperwork no contracts no liabilities, but all the productivity benefits can be banked? In addition, when the farm needs to demonstrate carbon neutral production in the next decade, this soil carbon will be essential to offset the balance of the farmers greenhouse gas emissions.

How much soil carbon can be accumulated?

The current level of organic carbon in soils across the northern grains zone is well below what can be achieved if we consider the impact of 100 years of conventional agriculture (Figure 1).

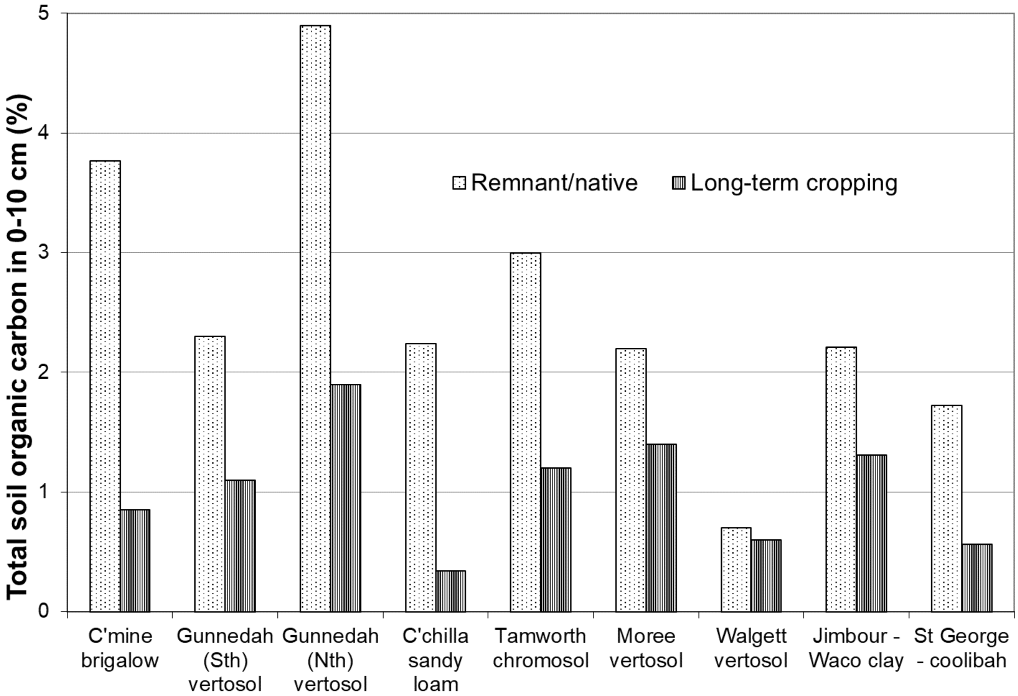

Figure 1. Impact of long-term cropping on soils of the northern grains zone (Lawrence *et al.,* 2017).

The SATWAGL long-term trial at Wagga (Chan *et al.,* 2011) has demonstrated the clear benefits of stubble retention, zero tillage and pasture phases for increasing soil carbon (Table 2). Over a 25-year period, stubble retention compared to burning was 2.2 t C/ha higher, zero tillage compared to conventional cultivation was 3.6 t C/ha higher, and a pasture rotation every second year was between 4.2 and 11.5 t C/ha higher than continuous cropping.

Many of these management practices, as well as reduced fallows, are now commonplace in grains systems of Australia. Soils have potentially reached a new (but low) steady state i.e. little change over time, provided the management does not change. A shift to a pasture-based farming system offers high potential for soil carbon gains (Figure 2) and its benefits, but a major consideration is obviously whether there is enough flexibility on-farm and profitability within the livestock sector to make this transition and to consider the potential for additional emissions from livestock.

Table 2. Change in soil organic carbon (SOC, kg C/ha over 0–0.30m soil depth) and final stock (t C/ha) under different rotation, tillage, and stubble and pasture management in the SATWAGL long-term field experiment (1979–2004) (adapted from Chan *et al.,* 2011)

Treatment	Tillage	Stubble	Rotation	SOC change (kg C/ha/year)	sig	Final stock (t C/ha)
T1	NT	SR	W/L	-52	n.s.	40.5
T2	CC	SR	W/L	-174	*	38.3
T3	NT	SB	W/L	-98	n.s.	39
T4	CC	SB	W/L	-176	*	35.4
T5	CC	SB	W/W	-278	**	33.6
T6	CC	SB	W/W-N	-193	*	34.6
T7	CC	SR	W/C-G	-2	n.s.	41.7
T8	NT	SR	W/C-M	257	*	48
T9	CC	SR	W/C-M	104	n.s.	43.1

NT, No tillage; CC, 3-pass tillage; SR, stubble retained; SB, stubble burnt; W/L, wheat/lupin rotation; W/C, wheat/clover rotation; W/W, wheat/ wheat; N, N fertiliser; G, grazed; M, mown. *$P < 0.05$; ** $P < 0.01$; n.s., not significant

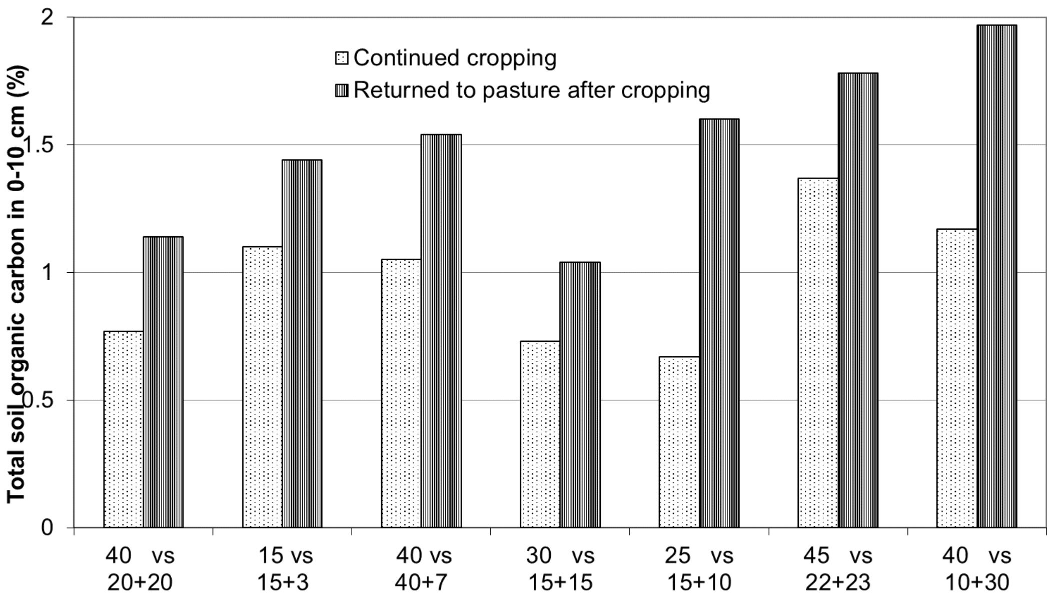

Figure 2. Changes in soil organic carbon levels after shifting from crop to pasture in the northern grains region (Lawrence *et al*., 2017). First value is the total duration of the cropping phase, second value is the duration of the cropping and pasture phases.

Over the past few years there has been an increase in the number of farmers and carbon aggregators making claims of increases in soil carbon that do not align with the published peer-reviewed science. Although conservative, the values presented in Table 3 are those estimated by the

Australian government official carbon model (FullCAM), showing likely increases in soil carbon in response to management. What is also seemingly ignored in claims of soil carbon increase, is the assumption this can continue in perpetuity, which defies the law of diminishing returns. The more carbon you sequester, the more carbon inputs you then require to maintain this level every year.

Table 3: Modelled soil carbon sequestration potential as stipulated and the Australian government ERF Offset method: Estimating Sequestration of Carbon in Soil Using Default Values, Methodology Determination 2015[1]

	Categories of sequestration potential (t C/ha/year)		
Project management activity	Marginal benefit	Some benefit	More Benefit
Sustainable intensification	0.03	0.16	0.45
Stubble retention	0.02	0.08	0.20
Conversion to pasture	0.06	0.12	0.23

[1]https://www.legislation.gov.au/Details/F2018C00126

Where soil has a low organic matter content, but high clay content and good rainfall (i.e. a high potential to increase soil organic matter), it is possible to achieve rates of soil carbon sequestration that exceed those presented in Table 3. The initial high carbon sequestration rates (i.e. the first 5 to 10 years with rates from 0.7 to 1 t C/ha/year in the top 30 cm when converting cropland to pasture; Meyer *et al.,* 2015; Robertson & Nash, 2013) will result in a new steady state after 10 years that matches the rainfall and management imposed. In contrast, the same conditions but with a high soil organic matter starting point, would only vary in direct relation to annual rainfall and distribution.

Another factor that limits the ability to determine changes in soil C is the large spatial variability that is found within a paddock. A high level of soil sampling is needed to detect differences in soil C between two time points. For example, Singh *et al.* (2013) found that a spatially optimised design, including stratification according to landform and yield mapping, needed at least 48 cores to reduce the standard error of measurement to less than 2 t C/ha at 0-30 cm in a 68 ha paddock. This is major limitation to cost-effectively verifying changes in soil C.

A new approach to managing soil organic matter in Australia

Perhaps there is a need to consider soil organic matter differently in the Australian context, by managing it more specifically for soil types by farming systems and also managing differently in high versus low rainfall periods. Sandy or granitic soils have very limited capacity to build soil organic matter as carbon is less protected to decomposition by microorganisms in these soil types, whereas clay soils generally have far higher potential to sequester carbon when rainfall is sufficient to maintain carbon inputs from stubble, roots or residual pasture biomass.

The key to building soil carbon, is to understand the capacity for the soil to store carbon in your specific environment (climate x soil type) and management system. This capacity varies considerably even within the same district. Therefore, we should not treat the landscape with a single sequestration potential, but target the areas that are low in carbon but high in sequestration potential e.g. the rehabilitation of degraded lands.

We should also be thinking of El Niño versus La Nina years quite differently, in that we have probably built more soil organic matter in eastern Australia during the recent La Nina, than in the previous three dry years put together. Higher rainfall year should focus on strategies that maximise the sequestration of carbon in our soils, and in low rainfall or drought periods, we focus on minimising the losses. Rather than focus on building soil carbon year by year, a longer-term approach would aim for a net increase in carbon over a 10 year period.

Short-term gain may mean long-term pain

Finally, whilst carbon neutrality is being strongly supported by the agricultural supply chain companies, there is an inevitable point where farmers will need to demonstrate progress towards lower emissions farming systems. Any increase in soil organic carbon you bank as a credit, will be negated by in-field emissions e.g. CO_2 from fuel, N_2O from N fertilisers or CH_4 from grazing livestock. Selling soil or tree carbon means that when the asset **value** leaves your property, you are left with the liability of maintaining what is now someone else's asset for the next 25 to 100 years (short term gain, long term pain). If the soil carbon is sold internationally, it also leaves the industry and the country, making any industry or national carbon sequestration targets increasingly difficult to achieve . Once the soil carbon is sold, the new buyer will be using it against their carbon footprint, which means that the farm will never again be able to use that soil carbon against their future liability, making their carbon neutral target increasingly impossible to achieve. The low risk option is to bank the inherent productivity benefit of improved soil health and don't sell your soil carbon, as you will need this asset for the day when you might need to table it against the balance of your own greenhouse gas emissions to meet supply chain demands.

References

Badgery WB, Mwendwa JM, Anwar MR, Simmons AT, Broadfoot KM, Rohan M and Singh BP (2020). Unexpected increases in soil carbon eventually fell in low rainfall farming systems. Journal of Environmental Management, 261, 110192.

Chan KY, Conyers MK, Li GD, Helyar KR, Poile G, Oates A and Barchia IM (2011). Soil carbon dynamics under different cropping and pasture management in temperate Australia: results of three long-term experiments. Soil Research, 49, 320-328.

Lawrence D. (2017) Informed carbon strategies on mixed farms: practices and carbon compared. Action of the Ground, Depart of Agriculture, AOTGR1-026, 34pp.

Love G (2005). Impacts of climate variability on regional Australia. In 'Outlook 2005. Conference proceedings, climate session papers'. (Eds R Nelson, G Love) pp. 10–19. (Australian Bureau and Resource Economics: Canberra, ACT, Australia)

Meyer RS, Eckard RJ, Cullen BR and Johnson IM (2015). Modelling to assess the sequestration and productivity benefits of soil carbon in grazing systems. Agriculture, Ecosystems and Environment 213, 272-280.

Robertson F. and Nash D (2013) Limited potential for soil carbon accumulation using current cropping practices in Victoria, Australia. Agriculture, Ecosystems & Environment, 165, 130–140.

Singh K, Murphy BW, and Marchant BP (2013). Towards cost-effective estimation of soil carbon stocks at the field scale. Soil Research, 50, 672-684.

Contact details

Peter Grace
Professor of Global Change
Queensland University of Technology
Email: pr.grace@qut.edu.au

Discussion session

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