JANDOWAE QLD
FRIDAY 2
AUGUST 2024

GRAINS RESEARCH UPDATE

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GRDC 2024 Grains Research Update Welcome

Welcome to our winter series of northern GRDC Grains Research Updates for 2024.

We are pleased to bring growers and advisers another series of Grains Research Update events tailored to deliver the latest research, development and extension (RD&E) to enhance the profitability and reliance of grain production.

The past year has continued to present unique challenges and opportunities, building on our experiences from 2023 where we faced below-average rainfall in parts of Queensland and northern New South Wales and close to average rainfall in southern NSW. To date, we have seen higher than expected December and January rainfall in many regions despite an initial dryer than average outlook.

These conditions highlight the importance of our ongoing RD&E efforts in developing resilient and flexible farming practices, allowing growers to adapt to the diverse weather and climate changes we see in our region.

Sustainability within the profitable farming systems framework continues to be front of mind for our sector and an important consideration when it comes to future market access, government policy and community expectations. One quarter of GRDC’s current RD&E investment portfolio has been identified as having direct environmental outcomes, with a significant portion contributing indirect environmental research outcomes. GRDC’s Sustainability Initiative articulates our focus on emerging interests in sustaining and improving our soil resource and working to better understand and manage greenhouse gas emissions. We look forward to sharing further results from these investments at future Grains Research Updates.

2023 was a significant year for GRDC. After extensive consultation with growers and the grains industry we announced our RD&E 2023-28 plan and a commitment to invest more than a billion dollars in research, development and extension to deliver improved outcomes for Australian grain growers.

Across our regions, this strategic investment involves addressing critical concerns highlighted by growers and advisers through the National Grower Network (NGN) and RiskWi$e forums.

In the northern region, GRDC and NSW DPI have entered a strategic partnership *Unlocking Soil Potential* aimed at developing novel products to capture, store and use more soil water in grain production. Other major strategic investments include the National Risk Management Initiative, known as *RiskWi$e*, and work designed to quantify the response of deep phosphorus placement and means of improving phosphorus use efficiency, farming systems research comparing and improving crop sequence gross margins and of course our ongoing, extensive and well known National Variety Testing program.

These represent just a few of the investments designed to ensure the most pressing profitability and productivity questions are addressed from paddock to plate. GRDC places a high level of importance on grower and adviser engagement and we encourage you to look for opportunities to participate in regional NGN forums that capture insights for future RD&E.

While we’re pleased to be able to facilitate plenty of face-to-face networking opportunities across this Updates series, we have also committed to continuing to livestream and record the main events for anyone who is unable to attend in person.

For more than a quarter of a century 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 our grains 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.

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

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. Please enjoy the Update and we look forward to seeing you again next year.

Graeme Sandral
Grower Relations Manager – North

Jandowae

GRDC Grains Research Update

Friday 2 August 2024

Jandowae Memorial Hall, George & Market Streets, Jandowae, QLD 4410

Registration: 8:30 AM for a 9:00 AM start, finish 2:40 PM

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	*GRDC*
9:10 AM	**Farming systems – profit over time and risk. An update on local farming systems research outcomes**	*Lindsay Bell (CSIRO)*
9:50 AM	**Amelioration strategies for dispersive soils in the northern grain's region. Multiyear trial results and repayment periods**	*Cameron Silburn (QDAF)*
10:25 AM	**MORNING TEA**	
10:55 AM	**SmartFarm testing of 270 paddocks across 90 farms over 10 years to better understand soil health changes and implications for management**	*Jayne Gentry (QDAF)*
11:20 AM	**Exploring soil organic carbon in long term cultivated vertosols on the Darling Downs**	*Meghan Barnard (UQ, PhD candidate)*
11:45 AM	**Mungbean harvest management – swathing, desiccation & MRL's**	*Jayne Gentry (QDAF)*
12:10 PM	**LUNCH**	
1:00 PM	**Fall armyworm impacts & thresholds in sorghum & maize – management options & guidance for 2024/25, plus consultant observations from last season**	*Joe Eyre (UQ), Melina Miles (QDAF) & Ross Pomroy (Nutrien Ag Solutions)*
1:45 PM	**Improving grain grower business resilience before, during and post drought. ARMonline tools to assist on-farm decision making by enabling outcomes of different cropping scenarios to be compared**	*Keith Pembleton (USQ)*
2:15 PM	**GHG emissions and intensities of our farming systems – what can we learn from long-term systems experiments?**	*Lindsay Bell (CSIRO)*
2:40 PM	**CLOSE**	

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Farming system performance over the short and long-term – impacts on profitability and sustainability indicators on the eastern Darling Downs, Qld.

Lindsay Bell[1], Jeremy Whish[1], Heidi Horan[1]

[1] CSIRO

Key words

crop rotation, soil water, economics, costs, legumes, break crops

GRDC code

DAQ2007-004RMX

Take home message

- Farming system decisions, particularly the soil water required for sowing, can have a large influence on system profitability over the short and long-term; differences of >$100/ha/yr occur regularly
- Systems using a wider diversity of crops can not only help manage biotic threats (e.g. diseases and weeds) but also be profitable compared with conventional systems
- While the last 6 years have presented a diverse range of seasons, this period in general has not favoured alternative farming systems compared to the *Baseline*
- Simulated predictions of relative profitability of the systems generally correspond well with those calculated from experimental data over the same period.

Introduction

The northern farming systems project has been examining how different farming system strategies impact on various aspects of the farming system since 2015. Across a diverse range of production environments, we have tested the impacts of changing:

1. The mix of crops grown by increasing the frequency of legumes or diversifying crop choices to provide disease breaks, or
2. The intensity of the cropping system by either increasing it by reducing the soil water threshold to sow more crops or by reducing it and only growing higher profit crops once the soil profile is full; and
3. The supply of nutrients provided to crops to target either average yields or to maximise yield potential in any season.

Despite now collecting 9 years of data on each of these different farming strategies, the full range of climatic conditions that are experienced across the region have not been captured. In particular, most sites have experienced periods of extremely dry seasons and some extremely wet seasons over the past 9 years, which is likely to bias or favour some particular farming systems. In addition to looking at the relative performance of these systems over our experimental period, simulation modelling can be useful to help explore how the different farming strategies might perform over the longer-term and under a wider range of climatic conditions. In this paper we compare APSIM predictions of system profitability and sustainability indicators over the long term along with predictions and observed data for the period 2015–2022. This paper reports specifically on results from the core farming systems site at Pampas on the Eastern Darling Downs, but similar analysis has been completed for other sites across the region.

System simulations and estimates of profitability

The different farming systems were simulated from 1957 to 2023 using APSIM. Soils used in simulations were those characterised at each location, and long-term climate data was sourced from the closest meteorological station. For each farming system at each location, the simulation was provided a list of crops (prioritised), their sowing window, and minimum soil water required to allow them to be sown. The rules dictating crop choices, their sowing dates and soil water thresholds at the Pampas site are outlined in Table 1; other sites vary in the crop choices and agronomic management employed.

Table 1. Rules associated with crop priority, crop choice, crop frequency and plant-available water threshold required to be sown applied in the *Baseline* and 4 modified farming systems at Pampas long-term farming systems experiment and in long-term simulation analyses.

System	Crop choice rules	Crop choices	Crop priority (1 – lowest; 3 - highest)	Soil PAW required to trigger sowing	Crop freq. limits (crops in years)
Baseline	No more than 3 winter cereals or sorghum consecutively ≥2 yrs between chickpea	Wheat	2	150	2 in 3
		Chickpea	3	150	1 in 3
		Barley	1	150	1 in 3
		Sorghum	2	150	3 in 4
		Mungbean	1	100	1 in 3
High legume frequency	*As above +*	*As above +*			
	Legume every second crop	Faba bean	2	150	1 in 3
		Field pea	1	150	1 in 3
		Soybean	3	200	1 in 3
Higher crop diversity	*As in Baseline +*	*As above +*			
	≥1 yr break after any crop ≥50% crops nematode resistant	Canola	3	200	1 in 3
		Sunflower	1	150	1 in 3
		Millet	1	120	1 in 4
		Maize	3	200	1 in 3
		Cotton	3	200	1 in 2
Higher crop intensity	*As in baseline*	Wheat	2	100	2 in 3
		Chickpea	3	100	1 in 3
		Barley	1	100	1 in 3
		Sorghum	2	100	3 in 4
		Mungbean	1	70	1 in 3
Lower crop intensity	*As in baseline*	Wheat	2	200	2 in 3
		Chickpea	3	200	1 in 3
		Sorghum	1	200	3 in 4
		Mungbean	3	150	1 in 3
		Cotton	3	200	1 in 2

Revenue, costs and gross margin for each crop were calculated using predicted grain yields and estimates of crop protection, non-N fertilisers and operational costs for each crop (see Table 2).

Fertiliser inputs were simulated dynamically based on a crop budget targeting a median yield (N fertiliser was costed at $1.30/kg N), and fallow herbicide applications ($15/ha/spray) were also predicted using the model based on the number of germination events that occurred.

Given the dynamic nature and range of different crops across these simulations, only a single crop sequence was generated over the simulated period. To allow analysis of the climate-induced variability, the system gross margins were aggregated over a sequential 6-year period; for example, from 1957–1962, 1958–1963 and so on. Hence, a comparison could be made between what the simulations predicted would occur during the experimental period of 2015–2021 at Pampas compared to more than 50 other 6-year periods. There were differences in how costs were calculated, with simulations assuming a set crop input cost while experimental data used actual costs incurred. This meant there was always a difference in the actual gross margins estimated from the model compared to the actual costs attributed in the experiments, hence we compare the magnitude of the change compared to the *Baseline* system in both cases to show their relative performance.

Table 2. Assumed prices (10-year average, farm gate after grading/bagging/drying) and variable costs for inputs and operations (e.g. seed, pesticides, starter fertilisers, sowing, spraying) and harvest costs (for viable yields only) for each crop simulated.

Crop	**Price ($/t product)**	**Variable crop Costs ($/ha)**	**Harvest costs ($/ha)**
Wheat	269	175	40
Durum	335	175	40
Barley	218	175	40
Chickpea	504	284	45
Sorghum	221	221	55
Mungbean	667	276	55
Faba bean	382	341	40
Field pea	382	341	40
Canola	503	351	70
Soybean	607	305	55
Sunflower	1052	365	55
Maize	250	218	55
Millet	564	350	70
Cotton	1800[A]	774	280

[A] Calculated on total harvest assuming 45% cotton lint turnout and 55% seed.

Experimental differences in system performance

After over 9 years of implementing the farming systems experiments at Pampas, the largest impacts on system profitability have been associated with changes in crop intensity – with these systems being both positive and negative compared to the *Baseline* over the life of the project depending on the season (Table 3). As of March 2024, the highest return has been produced by the *Low intensity* system – however, over one third of the crop income from this system came from a high yielding (8 bale/ha) dryland cotton crop in 2022/23. At the same point in time the *High intensity* system has produced a higher gross margin than *Baseline* by about $100/ha/yr. However, these systems have varied significantly in their relative profitability over the past 9 years (Figure 1). The *Low intensity* system has been the lowest accumulated gross margin for over half the time, only recovering to exceed the others in summer 2022. Similarly, during the dry seasons of 2018–2019, the relative profitability of the *Higher crop intensity* system declined, but this has recovered again during the wetter period of 2021–2022.

Systems that have changed the mix of crops by either increased frequency of legumes or diversified crop choices, or where nutrient supply has been increased have changed the net gross margin little, with differences after 9 years of less than $40/ha/yr. After the initial years, these small differences have also been relatively stable and small (since 2017, Figure 1). During the first 3 years, the *High legume* system had the highest GM but in later years this earlier advantage has been diminished. *Higher crop diversity* system has also achieved similar levels of gross margin over this period, but in the summer of 2023 (data not shown) a highly profitable sunflower crop has elevated its relative profitability at this point in time.

Table 3. Total income, input costs and gross margin achieved over 9 years and the contributing individual GM of each crop amongst different farming system strategies at Pampas between April 2015 and January 2023. Costs incurred during fallows are attributed at the end of the fallow prior to sowing the next crop. Crops: Wt – Wheat, Sg – Sorghum, Cp – Chickpea, Mg – Mungbean, Fb – Fababean, Cn – Canola, Ct – Cotton, Dr – Durum, By – Barley.

System treatment	***Baseline***	***High nutrient***	***High legume***	***High diversity***	***High intensity***	***Low intensity***
Total crop income ($/ha)	11340	11500	11320	11080	12830	12780
Total input costs ($/ha)	2160	2520	2040	2120	2650	1780
Total gross margin ($/ha)	9180	8980	9280	8960	10180	11000
Annualised GM ($/ha/yr)	**1020**	**1000**	**1030**	**1000**	**1130**	**1220**
Season	***Crop by Crop GM ($/ha)***					
Win 15	Wt 1539	Wt 1305	Fb 1806	Cn 1427	Wt 1636	Wt 1458
Sum 15	X	X	X	X	Mg 52	X
Win 16	X -138	X -138	X -136	X -143	X -78	X -132
Sum 16	Sg 1459	Sg 1436	Sg 1437	Sg 1393	Sg 1256	Ct 1743
Win 17	Cp 725	Cp 827	Cp 757	Cp 722	Cp 748	Wt 164
Sum 17	X	X	X	X	Sg 36	X
Win 18	X -57	X -57	X -57	X -57	X	X
Sum 18	Sg 999	Sg 1129	Sg 989	Ct 1293	Sg 495	X
Win 19	X	X	X	X	X -20	X
Sum 19	X	X	X	X	Mg -67	X
Win 20	X -99	X -99	X -114	X -80	X -48	X -136
Sum 20	Sg 910	Sg 895	Mg 910	Sg 640	Sg 467	Ct 2334
Win 21	Cp 1074	Cp 875	Wt 1116	Cp 1019	Cp 1988	X -18
Sum 21	Sg 892	Sg 955	Mg 690	Sg 879	Sg 997	Sg 1050
Win 22	Wt 1460	Wt 1318	Cp 1449	Dr 1680	Wt 1498	X -85
Sum 22	X	X	X	X	X	Ct 4629
Win 23	Wt 427	Wt 426	Wt 437	X	By 1220	X

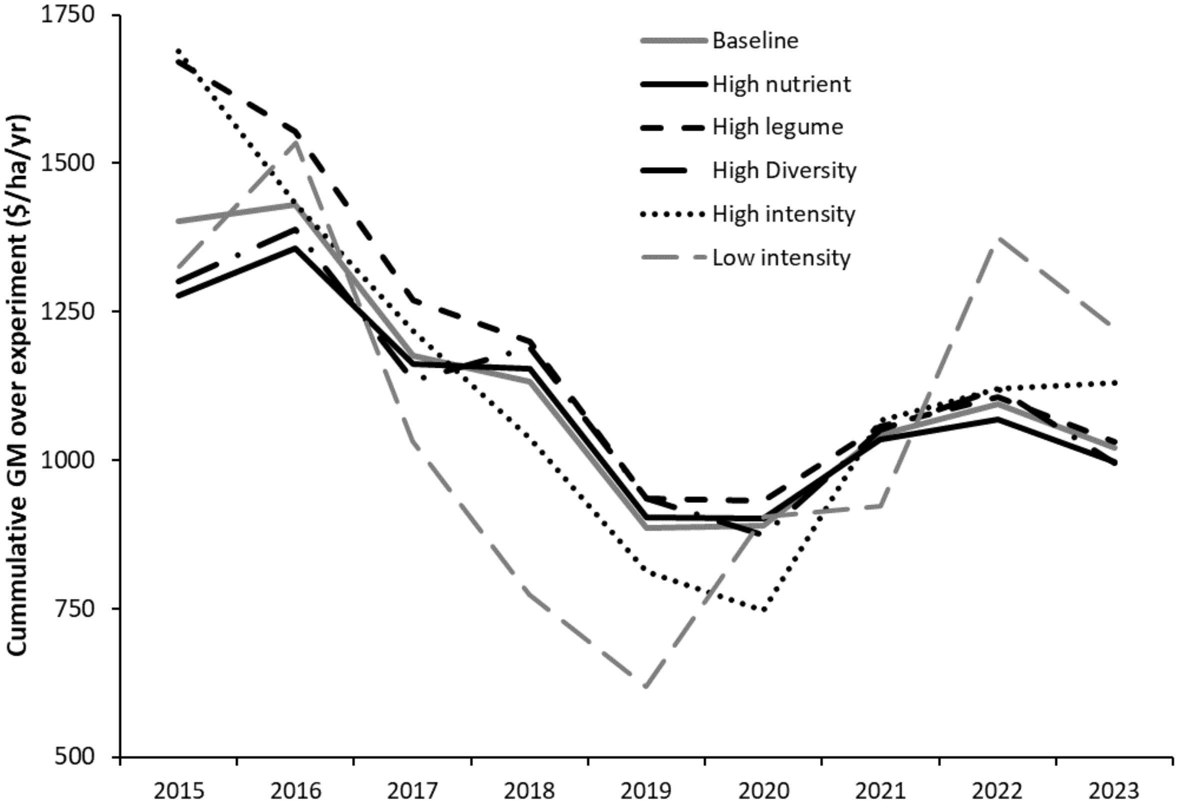
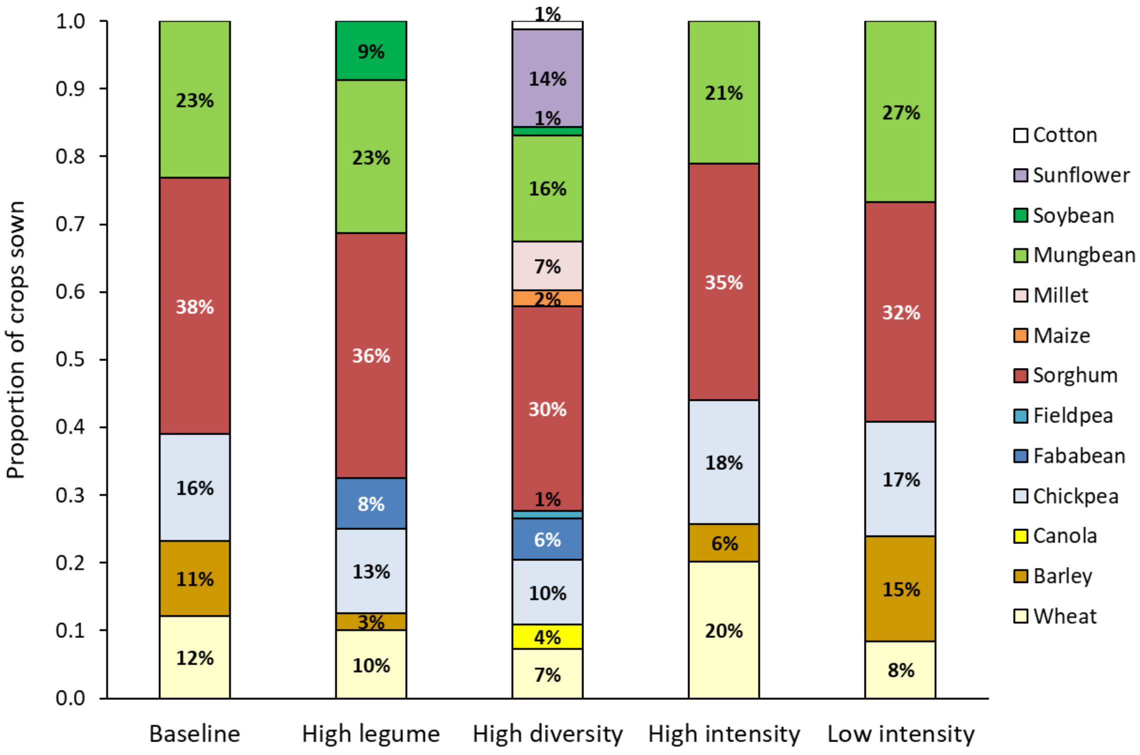


Figure 1. Cumulative gross margin (i.e. from Apr 2015 to April of each ensuing year) over 9 experimental seasons between different farming systems at Pampas.

Crop sequences & frequencies amongst long-term simulated systems

Long-term simulations of each of the experimental systems using the crop choices and rules described above resulted in quite distinct changes in the mix and intensity of crops grown over the long-term (Figure 2). At the Pampas site, applying our *Baseline* farming system rules predicted a long-term crop intensity of around 1.25 crops per year, or 5 crops in 4 years. About 40% of these crops were sorghum and 25% were mungbean; 20% were winter cereals and 15% were chickpea crops. By altering the system to apply our *Higher legume* frequency strategy resulted in a similar crop intensity but some additional soybean crops and faba bean replacing barley in the crop sequence (Figure 2). The *Higher crop diversity* system saw a drop in both legume and cereal frequency and less winter crops grown. Oilseeds increased to 20% of the crops grown – canola replacing barley and sunflowers replacing sorghum. Millet was also often substituted for mungbean as a summer double-crop and maize occasionally replaced sorghum. The *Higher intensity* strategy (*i.e.* lower soil water thresholds to sow crops) saw an increase in crop frequency by about 0.4 crops/yr (i.e. an additional 24 crops over the 60-year simulation), but the mix of crops was fairly similar to the *Baseline*. The *Lower intensity* system (*i.e.* a higher soil water threshold to sow crops) saw the crop frequency drop by 0.2 crops/yr – less than might be expected; the proportion of different crops also remained fairly stable except early-sown barley often replaced wheat.



Crops/yr	**1.27**	**1.24**	**1.29**	**1.69**	**1.10**
% winter	39	33	28	44	41
% cereal	61	49	47	61	56
% legume	39	51	34	39	44
% oilseeds	0	0	19	0	0

Figure 2. Cropping intensity (crops/yr) and the proportion of different crops under different farming system strategies at Pampas over the long-term (60 year) simulation.

Long-term predictions of system profitability

Figure 3 shows the range in average annual gross margin predicted over all the 6-year periods between 1957 and 2020 amongst the various simulated farming systems. These are arranged from the lowest to the highest to show the distribution of these predictions – this variability is driven only by climatic conditions as crop prices are held constant at 10-year average values.

The simulations suggest that across the full range of 6-year periods the *Baseline* system simulated here was never the most profitable choice. The *Higher intensity* system (grey circles) exceeds the profit generated in either the *Baseline* or *Low intensity* systems about 50% of the time, particularly under more favourable conditions. However, the *Higher intensity* system produces the lowest returns about 25% of the time when the overall profit is lowest. On the other hand, the *Low intensity* system (white circles) performs relatively well compared to *Baseline* and *Higher intensity* systems under the lower production and profit periods, exceeding them around 30% of the time.

The systems that alter the mix of crop (either *Higher legume* frequency or *higher crop diversity*) are predicted to generate higher profits over most periods. In general, they achieve similar potential profits to the other systems in the lower profitability periods, but potentially offer significant upside under more favourable conditions. In particular, these systems were able to offer a broader range of crop options to make use of seasonal rainfall and hence were more able to make use of additional crop opportunities when they occurred.

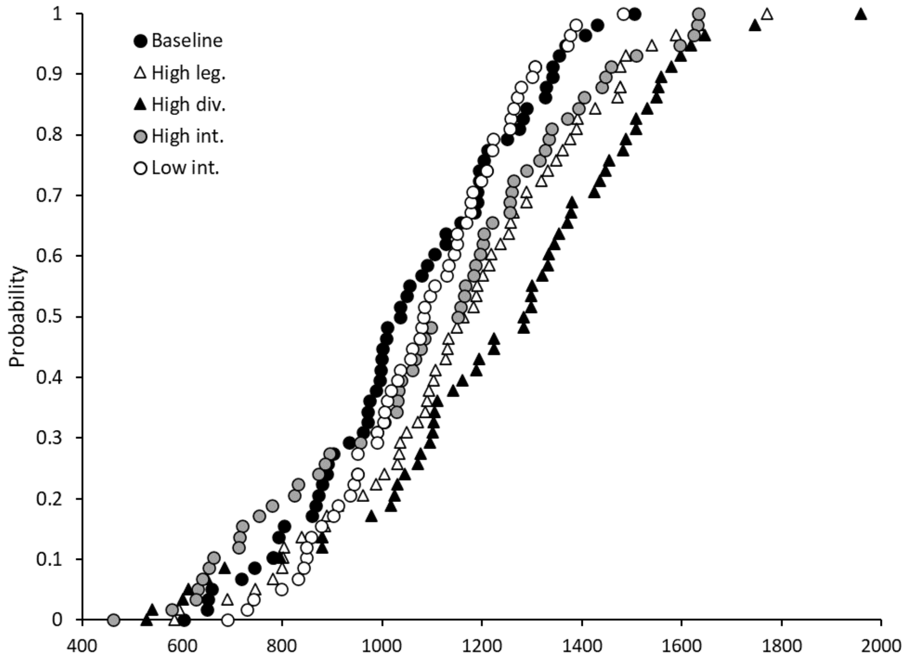


Figure 3. Distribution of simulated gross margin ($/ha, X-axis) (average of 6-years) over 60 years period (1957-2020) of different farming systems strategies at Pampas.

Short-term (experimental period) relative to the long-term

Comparing these long-term simulations with the experimental periods enables a comparison of observed differences in system profitability within a longer period. It also allows the comparison of differences in gross margin from both the experiments and the model predicted differences in gross profit. This paper compares the gross profit generated over the 2015–2022 period, as simulations are yet to be run the simulations for the whole period as reported above.

Figure 4 below presents similar results to those presented above in Figure 3, but this time just compares the predicted outcomes of each of the systems compared to the *Baseline* in each of the 6-year periods simulated. This shows that the modified farming systems frequently produce higher average returns (Figure 4); the *Higher diversity* systems produced higher returns 85% of the time, *Higher legume* systems 70% of the time, *Higher and lower intensity* systems about 60–70% of the time. However, the *Higher/Lower intensity* systems also had significantly lower profit in some periods compared to the *Baseline*.

The figure also includes what the model would have predicted to be the difference in gross margin between the *Baseline* and the altered systems over the experimental period (indicated by the larger symbols in Figure 4) – the vertical lines indicate the experimental findings. The model predicted that the *Higher intensity* system would be about $150/ha/yr behind, and this corresponded to the lower quartile of outcomes. However, this prediction is quite different from our experimental findings over this same period, where the *Higher intensity* system has generated around $60/ha/yr higher gross margin.

The observed and model predicted differences in gross margin corresponded well for the other systems. Over the experimental period the *Higher legume* system was predicted to be $70/ha/yr ahead of the *Baseline,* but the model predicted that over 90% of other 6-year periods would have generated further higher profits from this system. The *Higher crop diversity* system was predicted to produce slightly lower gross margin than the *Baseline* over the experimental period, but again over 90% of other periods would have generated relatively higher gross margins from this system. On the other hand, the *Lower intensity* has performed similarly to the *Baseline* over the experimental period, however this was around the median of these results, indicating that this experimental period was probably more favourable to this strategy than to the other systems.

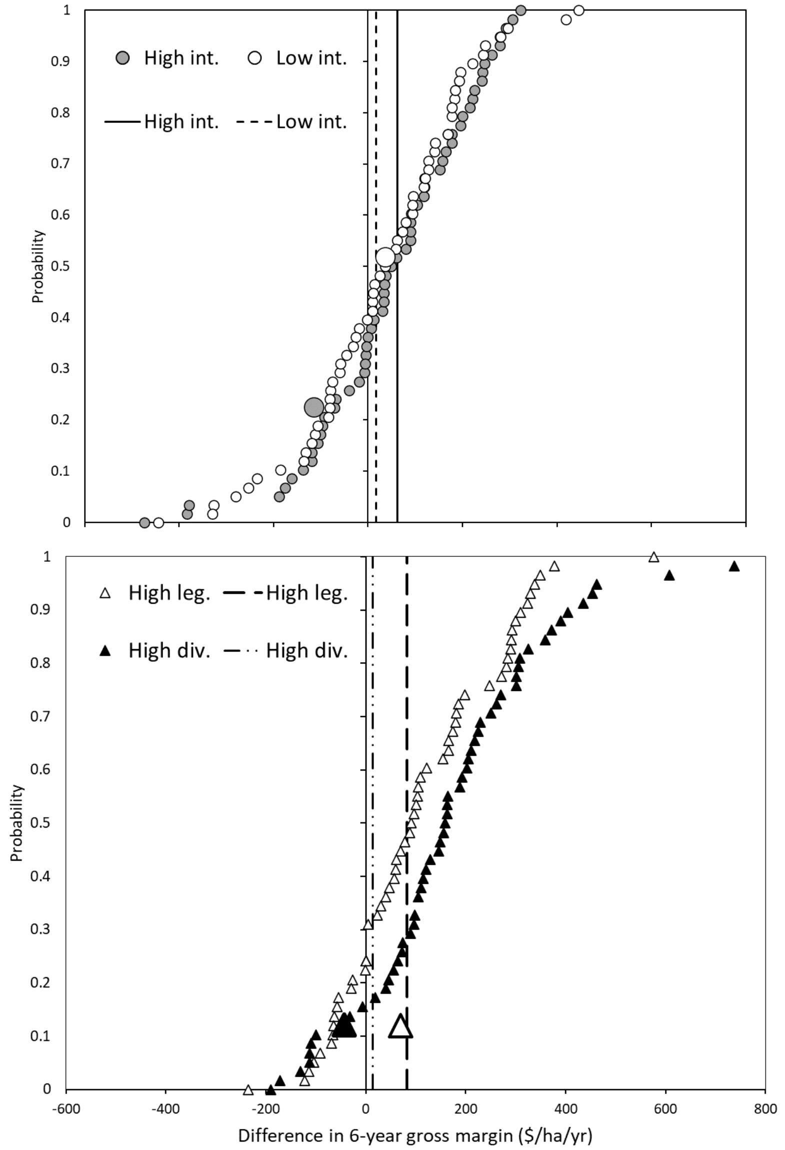


Figure 4. Difference in simulated 6-year gross margin between the *Baseline* and: (top) *Higher*- or *Lower Intensity* systems; and (bottom) *Higher legume* frequency or *Higher crop diversity* systems at Pampas between 1957 and 2023. Small symbols show the difference in simulated annual returns between the systems over 54 different 6-year periods. Vertical lines indicate the experimentally determined differences in gross margin between each of the systems and the *Baseline* (2015–2022), the large symbol indicates the simulated difference over that same period and where this would have sat on the wider distribution of simulated periods.

Conclusions

Farming strategies or systems need to consider resilience and relative performance across the full range of likely climate variability. While our experimental work has captured a range of seasons, the modelling here adds further insight into how the various farming system strategies might perform over the long-term. The modelling predictions of the relative differences over the past 6 years correspond well with our experimental data over the same period. While some of the alternative systems have not proved to be advantageous over this experimental period, the long-term analysis suggests there is potential to make use of a greater diversity of crops which could add significant upside under more favourable growing seasons. Further examination of the influence of price variability and risk on these findings is required to understand how robust different strategies are, and the key factors that might influence this.

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 acknowledge the various collaborators involved with collecting the experimental data and farmer collaborators for hosting the farming systems experiments across the region.

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Ameliorating soil constraints with deep ripping, gypsum, and soil organic matter – Queensland

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Key words

soil constraints, gypsum, organic matter, deep phosphorus, ripping

GRDC codes

UNE2209-001RTX, USQ1803-003RTX

Take home message

1. Improved crop nutrition (P) has been the main driver to significantly increase grain yield, especially in wetter than average seasons.
2. Gypsum treatments are improving yield over time, particularly in drier years.
3. Ripping alone has not improved yields and could be detrimental to soil structure and crop yields long term.

Background

Seventy-five percent of Australian soils have constraints that limit agricultural productivity. These constraints can be a biological, chemical or a physical feature of the soil that restricts root development and limits the crop's ability to utilise stored moisture and nutrients. The Queensland Department of Agriculture and Fisheries (DAF), Grains Research Development Corporation (GRDC), and the University of New England (UNE) have been investigating ameliorating soil constraints in the Northern Grains Region (NGR) of Australia.

The focus has been to determine if dispersion caused by sodicity, compaction and soil nutrition can be ameliorated by surface and subsoil (20 cm) ameliorants including gypsum, organic matter (OM), phosphorus (P) and physical interventions (e.g. ripping).

Six major trials (core sites) were established in 2019 from Drillham in southern Queensland to Parkes in New South Wales (NSW). This paper reports on the Queensland sites (Dulacca, Millmerran, and Talwood) up to 2023 that represent a total of 12 cropping years. Trials were established on growers' properties in 75 m^2 plots with each treatment replicated four times. Growers then managed these treatments as part of their normal paddock operations using commercial equipment. Various measurements have been recorded including yield, biomass, soil water and soil mineral nitrogen.

A network of large-scale on farm research (OFR) strip trials using commercial equipment were also implemented which are reported in this paper.

What was done?

This research focused on ameliorating soil constraints, specifically reducing dispersion caused by sodium as a constraint in the upper 50 cm part of the profile, as well as reducing compaction and immobile nutrient deficiencies in the top 20 cm of the soil profile. It is 'proof-of-concept' research intended to explore effects on soil water storage and grain yield under gypsum application rates designed to remediate the exchangeable sodium percentage (ESP) to <3% in surface and/or subsurface soil layers. The rates implemented are considerably higher than likely economically viable rates and were deliberately chosen to determine if subsoil amelioration, to improve soil structure, would result in improved production outcomes beyond the year of application.

The treatments included:

- Both physical and chemical ameliorants
- A range of options exploring impacts and/or interactions between tillage (shallow and deep)
- Deep placement of nutrients (inorganic and organic forms)
- Surface and subsurface applications of gypsum to reduce ESP to <3%
- Incorporating organic amendments (lucerne pellets in NSW and composted feedlot manure in QLD)
- Applying elemental sulfur (ES) to decrease soil pH (Table 1).

Table 1. Treatment structure for soil constraints core sites in southern Queensland.

Treatment No.	Description	Rip	Banded nutrient (fertiliser)	Gypsum	Organic matter	Elemental sulfur
1	Control					
2	S-Rip	Shallow				
3	S-Rip + BN	Shallow	Band			
4	S-Rip + BN + Surf Gyp	Shallow	Band	Surface		
5	D-Rip + BN	Deep	Band			
6	S-Rip + BN + Deep Gyp	Shallow	Band	Deep		
7	S-Rip + BN + (Surf + Deep) Gyp	Shallow	Band	Surface + Deep		
8	D-Rip + BN + Surf Gyp	Deep	Band	Surface		
9	S-Rip + BN + Deep ES + Surf Gyp	Shallow	Band	Surface		Deep
10	D-Rip + High BN	Deep	High-Rate Band			
11	D-Rip + Deep OM	Deep			Deep	
12	D-Rip + Deep OM + Deep ES	Deep				Deep
13	D-Rip + All	Deep		Surface + Deep	Deep	Deep

Note: S-Rip = shallow rip to 20 cm; D-Rip = deep rip to 40 cm; BN = banded nutrients @ 30 kg P/ha (monoammonium phosphate (MAP), product was Granulock Z);
High BN = 100 kg P/ha; OM = composted manure @ 10 t/h.

Surface gypsum treatments were spread onto the soil, and then incorporated by ripping to 20 cm. Actual application rates for gypsum varied with each site based on calculations that capture the required amount of calcium to lower the ESP to <3%, but the overall structure of the experiment stayed the same.

The applied gypsum rate for subsurface placement was banded at 20 cm depth. Only 50% of the total gypsum needed to remediate the whole 20 to 50 cm layer of soil was applied. This was due to the logistics of potentially needing to place upwards of 20 t of gypsum in that layer. For example, if a total of 20 t/ha of gypsum was theoretically needed to remediate the 20 to 50 cm layer, in this application 10 t/ha was applied.

Organic matter was included as it acts to limit soil aggregate dispersion and provides nutrients at depth, and whilst not reducing ESP, may also improve water holding capacity and pore stability. Gypsum rates that were often ≥15 t/ha were compared to subsoil composted feedlot manure applications of 10 t/ha. The application of ES is also being tested to dissolve calcium carbonate to produce gypsum in-situ, while deep-banded nutrients (N & P) were included to compare with the OM. Please refer to 'further readings' below for details regarding treatment implementation and engineering solutions.

Results

Each Queensland core site will be presented individually due to each site reacting differently to amelioration strategies. For details on soil characteristics at each site see Appendix. Detailed results and updates from the NSW core sites conducted in the project can be found online (see the link in further reading).

Millmerran core site

The Millmerran site has had a high intensity cropping rotation over the past four years (Table 2). This has enabled invaluable insights into which amelioration strategies are resulting in yield benefits (Table 3).

Table 2. Millmerran core site cropping rotation.

2019 Winter	2019/20 Summer	2020 Winter	2020/21 Summer	2021 Winter	2021/22 Summer	2022 Winter	2022/23 Summer	2023 Winter
Treatments implemented	Sorghum	X	Sorghum	Barley	X	Wheat	X	Wheat

Table 3. Millmerran cumulative grain yield for 4 of the past 5 crops (see notes).

Treatment No.	Treatment name	Yield (t/ha)	Delta (t/ha)	SE	*
1	Control	11.6	0.00	0.283	f
2	S-Rip	11.7	0.03	0.283	f
3	S-Rip + BN	13.2	1.58	0.283	de
4	S-Rip + BN + Surf Gyp	14.0	2.36	0.283	abc
5	D-Rip + BN	13.1	1.51	0.283	e
6	S-Rip + BN + Deep Gyp	13.3	1.69	0.283	cde
7	S-Rip + BN + (Surf + Deep) Gyp	13.9	2.26	0.283	abcd
8	D-Rip + BN + Surf Gyp	14.2	2.55	0.200	ab
9	S-Rip + BN + Deep ES + Surf Gyp	13.6	1.94	0.283	bcde
10	D-Rip + High BN	14.5	2.87	0.283	a
11	D-Rip + Deep OM	13.3	1.71	0.200	cde
12	D-Rip + Deep OM + Deep ES	13.5	1.84	0.283	bcde
13	D-Rip + All	13.5	1.85	0.283	bcde

Notes: Sorghum 2020/21 was not harvested and isn't included in this analysis.

Note: * Means with the same letters are not significantly different at P = 0.05. *Delta is difference from untreated Control.*

The sorghum crop grown in 2020/21 was unable to be harvested due to wet conditions followed by severe mouse damage, so it hasn't been included in the analysis. Above ground biomass cut at maturity of the crop was > +10% increases (data now shown) with several treatments (i.e. 3, 4, 7, 10) consistent with yield gains of harvested crops as outlined below.

The application of banded nutrients (*S-Rip + BN)* resulted in the most consistent yield benefit over the last four crops. The addition of deep applications of P increased yield significantly to a P limited soil. The *S-Rip* treatment did not significantly change yield hence it can be assumed that it was the applied P in *S-Rip + BN* that resulted in the increased yield. Treatments in combination with *BN* and *Surf Gyp* appear to be increasing yield further (significant result). The combination of these strategies resulted in an additional 0.6 t/ha of grain grown compared to '*S-Rip + BN'* (Table 3). Furthermore, this is 2.2 t/ha more grain grown than the control treatment over the past four crops. The additional surface gypsum is most likely increasing infiltration and improving plant establishment. Deep gypsum applications at this site have had no effect on yields to date.

The high nutrition treatment (*D-Rip + High BN)* is increasing yields the most compared to the control (2.87 t/ha), and shows that this soil is very P limited and most likely one of the biggest constraints to improving yields (Table 3). Nitrogen input in the *High BN* treatment is also greatest, with 280 kg N/ha applied initially.

The organic matter (*OM*) treatments have performed close to the high inorganic nutrition treatment however the 2022 wheat crop didn't yield very well which has impacted the cumulative yield results. This was most likely due to the high yield potential season in which there was less available nutrition in a short period of time to support a higher yield. Above ground N uptake was greatest in the *High BN* treatment (152 kg N/ha), while the high OM treatment was 76 kg N/ha.

Dulacca core site

The Drillham site has had a very intensive cropping rotation with five crops grown in the last 4 years. The intensity increased in the last 18 months due to the increased rain, with three crops grown in the past two years (Table 4).

Table 4. Dulacca core site cropping rotation.

2019 Winter	2019/20 Summer	2020 Winter	2020/21 Summer	2021 Winter	2021/22 Summer	2022 Winter	2022/23 Summer	2023 Winter
Treatments implemented	X	Wheat	X	Wheat	X	Barley	Sorghum	Wheat

Table 5. Dulacca cumulative grain yields for the past 5 crops.

Treatment No.	Treatment name	Yield (t/ha)	Delta (t/ha)	SE	*
1	Control	11.43	0.00	0.23	e
2	S-Rip	11.86	0.43	0.46	de
3	S-Rip + BN	11.39	-0.04	0.46	e
4	S-Rip + BN + Surf Gyp	11.68	0.25	0.46	de
5	D-Rip + BN	12.22	0.79	0.46	bcde
6	S-Rip + BN + Deep Gyp	12.56	1.13	0.46	bcd
7	S-Rip + BN + (Surf + Deep) Gyp	12.05	0.62	0.46	cde
8	D-Rip + BN + Surf Gyp	13.26	1.83	0.46	abc
9	S-Rip + BN + Deep ES + Surf Gyp	12.22	0.79	0.46	bcde
10	D-Rip + High BN	12.42	0.99	0.46	bcde
11	D-Rip + Deep OM	12.18	0.75	0.46	bcde
12	D-Rip + Deep OM + Deep ES	13.38	1.95	0.46	ab
13	D-Rip + All	14.15	2.72	0.46	a

Note: * Means with the same letters are not significantly different at P = 0.05. *Delta is difference from untreated Control.*

The yields of the most recent crops, sorghum 2022/23 and wheat 2023, were compromised from poor crop establishment with the sorghum double cropped into the heavy barley stubble, and the following wheat exhibiting high levels of crown rot. No single treatment factor such as *BN, OM or D-Rip* has provided the main yield benefit over the past 4 years. However, there are indications that treatments with *Deep Gyp* are helping to increase yield. Treatment *D-rip + All* is the highest yielding treatment, yielding 2.72 t/ha higher than the control (Table 5).

Talwood core site

The Talwood site has had a low cropping intensity over the past four years with only two crops grown on the trial since establishment (Table 6). As a result, there is less confidence in yield trends, however trends to date are promising.

Table 6. Talwood core site cropping rotation

2019 Winter	2019/20 Summer	2020 Winter	2020/21 Summer	2021 Winter	2021/22 Summer	2022 Winter	2022/23 Summer	2023 Winter
Treatments implemented		X	Sorghum	X	Sorghum Cover crop	Wheat	X	X

Table 7. Talwood cumulative grain yield for the past 2 crops.

Treatment No.	Treatment name	Yield (t/ha)	Delta (t/ha)	se	*
1	Control	7.23	0.00	0.165	c
2	S-Rip	7.58	0.35	0.285	bc
3	S-Rip + BN	8.85	1.62	0.285	a
4	S-Rip + BN + Surf Gyp	8.57	1.34	0.329	a
5	D-Rip + BN	8.95	1.72	0.285	a
6	S-Rip + BN + Deep Gyp	8.27	1.04	0.285	ab
7	S-Rip + BN + (Surf + Deep) Gyp	8.53	1.30	0.285	a
8	D-Rip + BN + Surf Gyp	9.01	1.78	0.285	a
9	S-Rip + BN + Deep ES + Surf Gyp	8.42	1.19	0.285	a
10	D-Rip + High BN	8.99	1.76	0.285	a
11	D-Rip + Deep OM	6.88	-0.35	0.285	c
12	D-Rip + Deep OM + Deep ES	5.58	-1.65	0.285	d
13	D-Rip + All	5.32	-1.91	0.285	d

Note: * Means with the same letters are not significantly different at P = 0.05. *Delta is difference from untreated Control.*

To date, including *BN* in the treatments appears to be the main driver of yield. The addition of *BN* in the treatments has increased yields by at least 1.62 t/ha (Table 7). The addition of gypsum at this site hasn't provided any clear yield benefits to date. This is most likely due to the low cropping intensity during the experiment to date. The *OM* treatments have performed poorly to date due to early flowering caused by high available nutrition in the sorghum 2020/21 crop. In addition, these plots were heavily infested with midge and mouse damage, which has resulted in reduced cumulative yields to date.

Economics

At the inception of this project it was established very much as "what-if" scenarios about the potential to reengineer sodic soils. The application rates of ameliorants applied was set up to target 3% ESP in the top 20cm of soil, and reduction in half of the soil mass from 20-50 also to a 3% ESP. Hence the application rates were not intended to be economically viable.

The research has been running long enough to start examining the economics of subsoil intervention. While sensible economic assumptions have been made, each grower will have a different economic situation which should be considered.

Treatment costs were estimated from a combination of previous studies, grower estimates, expert opinion, and average market price of inputs. The application costs include amendment material costs at farm gate (product prices, transport and handling) and costs associated with applying amendments including labour (paid or imputed) and all machinery costs (operation and depreciation), derived from grower estimates and/or contract machinery operation prices. Updated crop variable running costs based on a generalised agricultural management plan (using practicing agronomists) per crop for a model area in the centre of the northern region (Moree) and applied this globally throughout all sites. Cumulative net return has been calculated for each intervention at all three core sites. We have also estimated the payback period for each intervention for each site (Table 8).

Millmerran

Four-year return (four crops) resulted in some treatments with cumulative incomes reaching $550 to $1000/ha higher than the control. This site responded strongly to deep applications of banded nutrients (Figure 1). These treatments replaced the depleted subsoil P but required ripping interventions to incorporate. Some responses to OM amendments and surface gypsum applications were also achieved. It is worth noting that the availability of relatively cheaper composted manure at this location made the payback period much shorter for the OM treatment (Table 8).

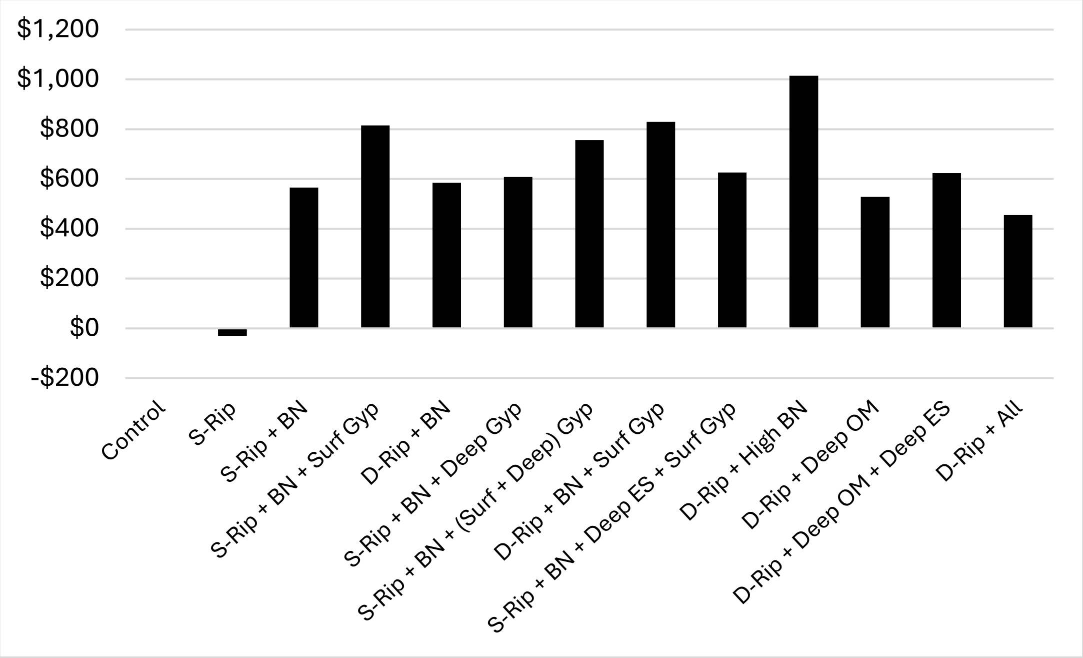

Figure 1. Millmerran core site cumulative net returns from crops grown between 2020 and 2023 for subsoil amelioration treatments.

Dulacca

Four-year return (five crops) resulted in some treatments with cumulative income of up to $762 return per ha higher than the control treatments (Figure 2).

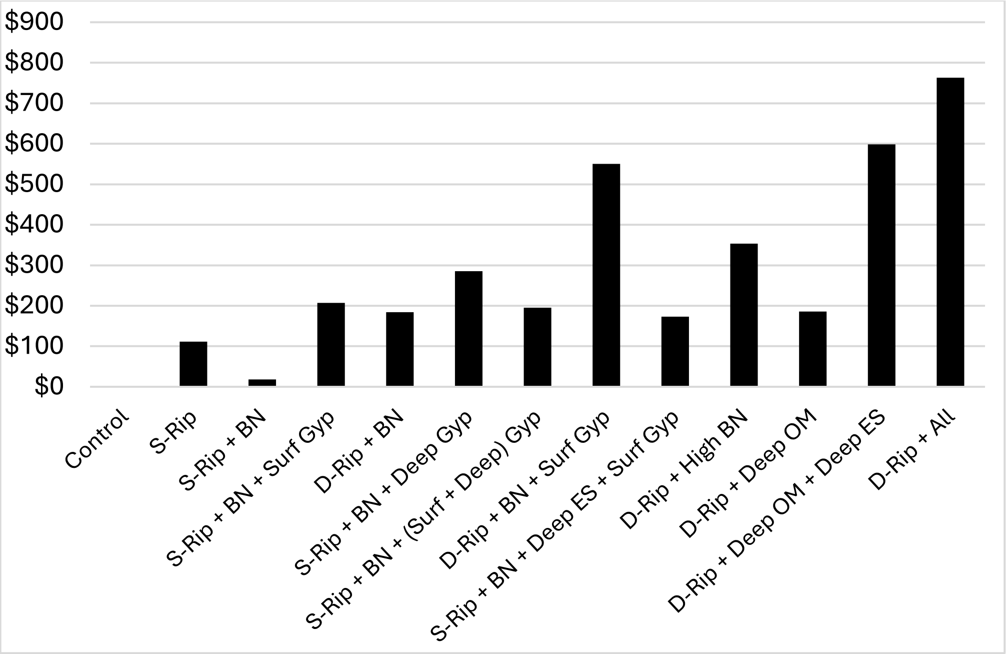

Figure 2. Dulacca core site cumulative net returns from crops grown between 2020 and 2023 for subsoil amelioration treatments.

Talwood

With only two crops over the four years, the returns ranged from a net cost of $300/ha for some of the high-rate treatments where treatments have depressed yields, to a net benefit of $667/ha over the control (Figure 3). The deep and surface applied gypsum and deep P treatments also performed quite well, with higher yields compared to the control treatments. Combinations of ripping and additional nutrition (deep) in the form of fertiliser appear to be having benefits at this site.

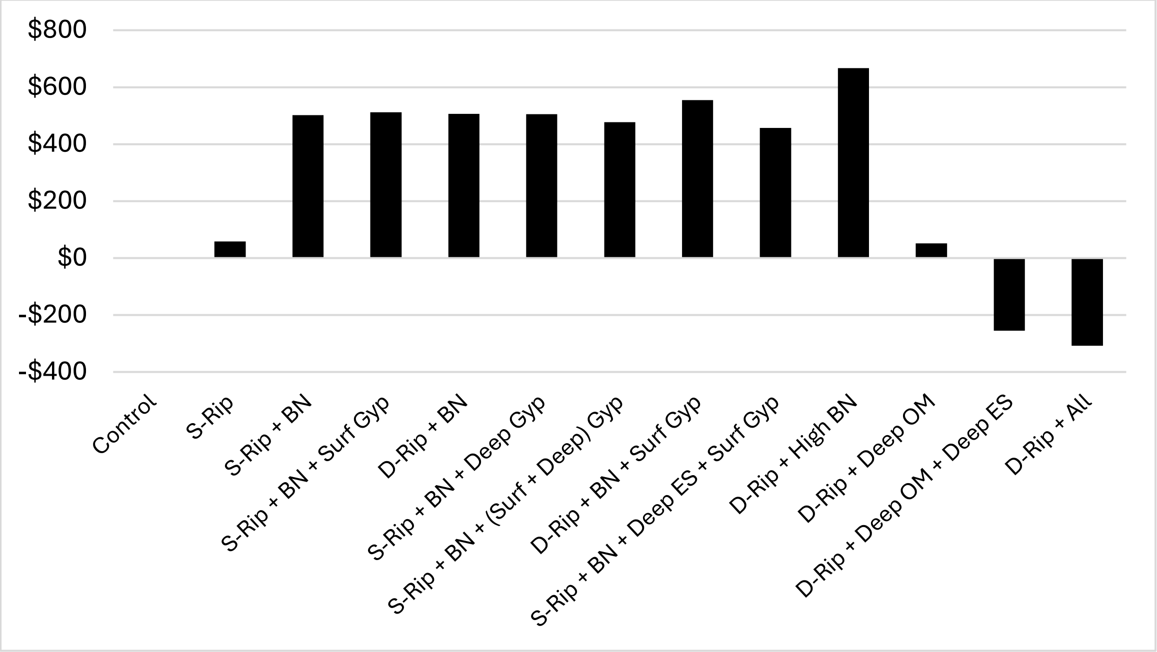

Figure 3. Talwood core site cumulative net returns from crops grown between 2020 and 2023 for subsoil amelioration treatments.

Payback period

The payback period is strongly linked to the potential productivity of each environment. In areas with lower yield potential, the relative benefits are lower and payback periods correspondingly longer. Soils with higher buffering capacity also require a longer payback time, which reflects the higher inputs that have been required to significantly change the soil properties.

Based on the last four years, the most economically viable management strategies involve low capital expenses on inputs with some returns suggesting tillage and nutrient treatments are paying the bills (Table 8). It is subsequently worth considering that the cost in diesel to rip to depth without adding the necessary amendment is unlikely to be recovered. Similarly, repeated smaller gypsum/OM applications coupled with deep ripping is cost prohibitive. Hence, a single, large addition may ultimately be the best return on investment. There remains uncertainty over the pathway for best amelioration practices, so growers are cautioned to investigate in smaller stages to validate those outcomes for themselves.

Table 8. Payback period (years) of initial amelioration investment based on the average net return following the first four years following application. Variable expenses are generalised and based on commonly recommended inputs. Returns are relative to the yield and quality of harvested grain.

Treatment	Payback period (years)		
	Talwood	Dulacca	Millmerran
Control	-	-	-
S-Rip	3	2	-6
S-Rip + BN	2	43	1
S-Rip + BN + Surf Gyp	8	19	4
D-Rip + BN	2	6	2
S-Rip + BN + Deep Gyp	12	25	10
S-Rip + BN + (Surf + Deep) Gyp	8	22	5
D-Rip + BN + Surf Gyp	18	19	10
S-Rip + BN + Deep ES + Surf Gyp	19	52	13
D-Rip + High BN	4	9	3
D-Rip + Deep OM	60	17	6
D-Rip + Deep OM + Deep ES	-31	13	12
D-Rip + All	-55	23	33

On farm research (OFR) sites

The use of amendments on most (83%) of the OFR sites sampled using a plot header resulted in yield increases. These increases ranged from 20 to 83%, with an average 41% increase for the best performing treatment at each site. These results are drawn from the drier 2023 season where there were some poor yields, so small yield gains led to large percentage increases. An initial review of results to date shows the best treatments varied with the individual sites. Key constraints for each soil are outlined in Table 9.

Table 9. Brief site soil type description for responsive on farm research sites 2023.

Site	Description
Parkes	Red Sodosol with moderately sodic, non-dispersive topsoil, neutral pH and high bulk density over a sodic, dispersive and alkaline subsoil with high bulk density. P availability (Colwell) is 32 mg/kg in the surface (0-10cm) and 6 mg/kg at depth (10-20cm)
Armatree	Red Sodosol with moderately sodic and dispersive topsoil, acid pH and high bulk density over a sodic, dispersive and alkaline subsoil with high bulk density. P availability (Colwell) is 40 mg/kg in the surface (0-10cm) and 8 mg/kg at depth (10-20cm). Moderate salinity throughout the profile.
Millmerran	Grey/brown Vertosol with sodic, non-dispersive topsoil, neutral pH. Sodic at depth with dispersion increasing with alkaline pH. P availability (Colwell) is 28 mg/kg in the surface (0-10cm) and 6 mg/kg at depth (10-20cm)
North Star	Red Chromosol with non-dispersive soil throughout the profile. The profile is generally not sodic with an increase in patches at depth. pH is generally neutral but alkaline at depth. P availability (Colwell) is 28 mg/kg in the surface (0-10cm) and 8 mg/kg at depth (10-20cm)
Croppa Creek	Red/grey soil (variable site) with a non-sodic surface increasing to sodic at depth but generally not dispersive. Neutral pH in the surface increasing to highly alkaline at depth with some salinity (EC).

At Millmerran the addition of surface lime and gypsum with ripping increased yield by 33% compared with deep ripping alone, while at Armatree, lime increased yield by 28% while gypsum was less effective. Both sites were highly compacted and the addition of calcium as lime to lower pH of surface soils seems to have improved the maintenance of soil structure following disturbance.

At North Star, deep P with ripping resulted in an 83% yield benefit. This is consistent with the generally low levels of available P at depth and the reliance on stored moisture this season.

At Parkes, the best treatments in a season with cool and moist grain filling conditions had a 40% increase in yield compared with controls. The largest responses were to high rates of OM (manure, biosolids etc) when combined with lime or gypsum, all without ripping. These treatments appear to have had significant positive influence on the structure and nutrition in this lighter but compacted red soil.

Deep ripping alone, with no amendment, also provided substantial benefits at some sites (e.g. Parkes, Millmerran and Armatree). However, core site data indicates that these treatments may be short lived, so recommending this practice has potential implications for long term soil structural decline and loss of soil organic carbon; care should be taken.

For the five sites measured with hand harvests in strips, two produced statistically significant results. At Croppa Creek, the manure, gypsum and deep fertiliser in combination provided the greatest benefits for yield with an 114% increase (double) for canola. Gypsum by itself and manure by itself had little benefit but the combination was important. This suggests that where deep soil constraints occur, improving structure can help with plant access to water but nutrition must support increased yield potential. The North Star site was variable but had a trend to increased yield with added P and gypsum.

Several of the OFRs that demonstrated yield responses required a combination of amendments (e.g. extra nutrition and gypsum together), with little response to individual amendments. If looking at amending a strip or paddock, consider including combinations of amendments depending on your site.

Finally, it is important to note that improving available water through soil structural improvement isn't worth much if you don't have the nutrition to support additional growth. Core site experiments have responded to structural treatments, but all these treatments had additional nutrition supplied.

Implications for growers

The results to date suggest that nutrition is the main driver for yield improvement at two of the three major Queensland sites (Millmerran and Talwood). Growers need to ensure that crops are provided with sufficient nutrition and to review those nutrition needs once other ameliorants are used to increase yield potential.

It is also evident that ripping by itself provides little to no long-term benefit. At some sites ripping has increased yield in the crop following the ripping event, however this benefit is usually short lived and core site data is beginning to show negative crop responses two to three years later. Ripping alone should be avoided unless it is used to introduce a longer-term ameliorant.

The most common and perhaps the most economical strategy will be improving soil fertility through boosting plant available N supplies in combination with deep fertiliser P. Before growers start on deep gypsum or manure applications, investigation of soil structural stability together with assessment of fertility should be conducted for targeting best potentially responsive sites. Starting with on-farm research with test-strips is a prudent approach before significant investments in ameliorating applications.

Each site is different, and so there is no single recipe to follow. Soils with a high buffering capacity or CEC will require higher rates of amendments to make a significant change, which will require higher cost that may not be reflected in greater gains in grain yield. This needs to be taken into consideration when deciding to use amendments in a paddock.

For growers beginning their soil amelioration journey, soil testing should be the first step to determining possible constraints and consequently amendment options. These ameliorants can have a high cost and appear to work best in combinations, such as deep P and gypsum. So, once ameliorant options have been identified from these soil test results, test strips should be used for several growing seasons to assess their impacts.

Further reading

Dispersive soil manual - Managing dispersive soils: practicalities and economics – northern region. https://grdc.com.au/resources-and-publications/all-publications/publications/2023/dispersive-soil-manual

GRDC Grains Research Update paper - Soil constraints project - an update on the economic response of long term soil amelioration strategies – February 2024 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/soil-constraints-project-an-update-on-the-economic-response-of-long-term-soil-amelioration-strategies

GRDC Grains Research Update paper - Ameliorating sodicity; what did we learn about ameliorating sodicity constraints with a range of treatments? Yield responses to ripping, gypsum and OM placement in constrained soils – March 2022 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/03/ameliorating-sodicity-what-did-we-learn-about-ameliorating-sodicity-constraints-with-a-range-of-treatments-yield-responses-to-ripping,-gypsum-and-om-placement-in-constrained-soils

GRDC Grains Research Update, online (recording) - Ameliorating sodicity – Central & Northern NSW & Qld - March 2022. https://grdc.com.au/events/past-events/2022/march/grdc-grains-research-update,-online-ameliorating-sodicity-central-and-northern-nsw-and-qld

GRDC Grains Research Update, online (recording). The economics of ameliorating dispersive soils – May 2024. https://grdc.com.au/events/past-events/2024/05/grdc-grains-research-update-online-the-economics-of-ameliorating-dispersive-soils

GRDC Grains Research Update paper - Amelioration for sodicity - deep ripping and soil amendment addition across NSW and Qld. Engineering challenges. Yield responses to ripping, gypsum and OM placement in constrained soils – February 2021. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/amelioration-for-sodicity-deep-ripping-and-soil-amendment-addition-across-nsw-and-qld.-engineering-challenges.-yield-responses-to-ripping,-gypsum-and-om-placement-in-constrained-soils

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.

Appendix – details of soil characteristics at sites

Location: Dulacca

Soil type: Grey/Brown Vertosol, surface soils not spontaneously dispersive but subsurface highly dispersive.

Depth	pH	pH	EC	ECEC	ESP	Cl	Colwell P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)	%	(mg/kg)	(mg/kg)
0-10	8.5	7.7	0.21	29.8	9	43	9
10-20	8.8	7.8	0.25	30.3	13	53	14
30-40	8.1	7.3	0.46	35.3	20	102	4
60-70	6.8	6.7	0.66	34.1	26	275	8

Location: Millmerran

Soil type: Grey/Brown Vertosol, surface and subsurface soils not spontaneously dispersive, very compact soil through the profile.

Depth	pH	pH	EC	ECEC	ESP	Cl	Colwell P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)	%	(mg/kg)	(mg/kg)
0-10	6.6	6.3	0.15	17.7	13	153	38
10-20	8.7	7.4	0.24	23.2	14	330	5
30-40	6.9	6.2	0.38	31.4	22	428	3
60-70	6.4	5.5	0.43	35.5	25	457	2

Location: Talwood

Soil type: Red/Brown Vertosol with surface soils not spontaneously dispersive, subsurface highly dispersive at 60-70cm.

Depth	pH	pH	EC	ECEC	ESP	Cl	Colwell P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)	%	(mg/kg)	(mg/kg)
0-10	8.3	7.6	0.17	35.5	11	22	18
10-20	8.7	7.9	0.23	39.3	10	26	3
30-40	8.9	7.8	0.36	39.4	18	73	2
60-70	9.2	7.9	0.44	40.7	24	163	2

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Soil health stocktake – Queensland

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Key words

soil health, nitrogen, carbon, phosphorus, potassium

Take home message

- Total Organic Carbon: average across all locations in central and southern Queensland was 1.21% (0–10 cm) and 0.89% (10–30 cm)
- Phosphorus: 57% of paddocks (270) recorded low levels of phosphorus (< 7 mg Colwell P/kg and < 50 mg BSES P/kg) in 10-30cm soil layer that indicate a potential response to the application of deep phosphorus
- Potassium: 35% of paddocks (270) recorded low levels of exchangeable potassium in 10-30cm soil layer that indicate a potential response to the application of deep potassium.

Background

Soil health can be defined as, ‘the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans’ (Natural Resources Conservation Service, 2024). Soil health is complex as it is driven by physical, chemical and biological properties, processes and their interactions with farming practices. Hence, soil health and how it is impacted by management is best considered in a holistic manner.

Reduced soil organic matter and soil fertility where native vegetation has been removed are key indicators of soil health decline in Australia. This decline is most significant on soils that are under long-term cultivation (Dalal & Mayer 1986) and is becoming a major constraint to the productivity and sustainability of Australian farms.

Soil sampling is one way of investigating soil properties. This is often conducted by an agronomist who provides a recommendation to the grower outlining the required fertiliser application for the subsequent crop. Without an understanding of the soil analysis and/or its connection to soil health, growers cannot make informed management decisions. The ‘Healthier soils through better soil testing’ project was funded in February 2022 by the Department of Agriculture and Fisheries Queensland and the Australian Government’s National Landcare Program to improve management of soil health.

What was done

The project was delivered across 2022–2024 with three main activities: soil testing, action learning workshops, and participatory action (on-farm) research. This report will focus on the soil testing results. The key functions of soil health and the indicators assessed were:

- The soil’s ability to maintain soil organic matter (measured by soil organic carbon)
- The soil’s ability to supply nutrients for plant growth (measured by available nitrogen, phosphorus and potassium)
- Good soil structure (measured by dispersion and exchangeable sodium percentage)
- Free from toxicities (measured by salinity and chlorides)

- Free from pathogens (measured by Predicta®B)
- Levels of arbuscular mycorrhizal fungi (AMF) (measured by Predicta®B).

Ninety cropping properties were identified by the project team across southern and central Queensland. The project team soil sampled three paddocks on each of these properties (a total of 270 paddocks) (Figure 1). The three paddocks were identified via a one-on-one semi-structured interview with the grower (and their agronomists where appropriate). These interviews assisted the project team to target soil sampling to investigate the grower specific questions and so maximise their learning. Paddocks were chosen to compare the impact of different scenarios on soil properties such as differences in management practices, soil type, or length of cultivation. The project team then conducted soil sampling with rigorous protocols to ensure scientific integrity of the data. Where possible this process was done with the grower in their own paddocks, so the grower could see and feel their own soil beyond the surface.

Figure 1. Map of participating properties indicated by markers.

The soil sampling procedure took six cores from each paddock. Each core was segmented into 0–10, 10–30, 30–60, 60–90, 90–120 (if possible) cm layers, with each layer from the six cores bulked. The 0–10 cm and 10–30 cm layers were analysed for pH (H_2O), pH ($CaCl_2$), Total Organic Carbon, electrical conductivity, chloride, nitrate nitrogen (N), ammonium N, dispersion, exchangeable cations (aluminium, calcium, magnesium, potassium, sodium), total N, Colwell phosphorus, phosphorus buffering index (PBI) and BSES phosphorus. The 30-60, 60-90, 90-120 cm layers were analysed for pH (H_2O), pH ($CaCl_2$), electrical conductivity, chloride, nitrate nitrogen (N), ammonium N, dispersion and exchangeable cations (aluminium, calcium, magnesium, potassium, sodium). A further sample (0–15 cm depth) was taken from each paddock and analysed using Predicta®B DNA-based soil testing service.

Results

The data collected provided a comprehensive benchmark of soil physical, chemical and biological properties of Queensland cropping paddocks. Several key insights were drawn from the cumulative data.

1. Plant available N (kg/ha) (measured as nitrate nitrogen and ammonium nitrogen and calculated using a bulk density of 1.3) indicated that 204 of the 270 paddocks (76%) had below 100 kg N/ha in the 0–90 cm part of the soil profile that grain crops typically access. 143 paddocks (53%) had very low levels of 50 kg N/ha or less. This is important because ~45 kg N/ha is required to grow 1 t wheat/ha at 13% protein, while many of the growers were targeting 2–3 t/ha (data not shown).

2. TOC levels (method 6B1 – Heanes wet oxidation) varied across geographical locations. The western locations recorded lower TOC. The lowest 0.37% TOC in 0–10 cm was recorded at St George (long term cropping paddock, low Colwell phosphorus, low annual rainfall). The highest level of 4.44% in the 0–10 cm layer was recorded at Toowoomba (long term forage pasture paddock with very high Colwell phosphorus and higher long-term rainfall). The average across all locations was 1.21% (0-10cm) and 0.89% (10–30 cm) (Figure 2).

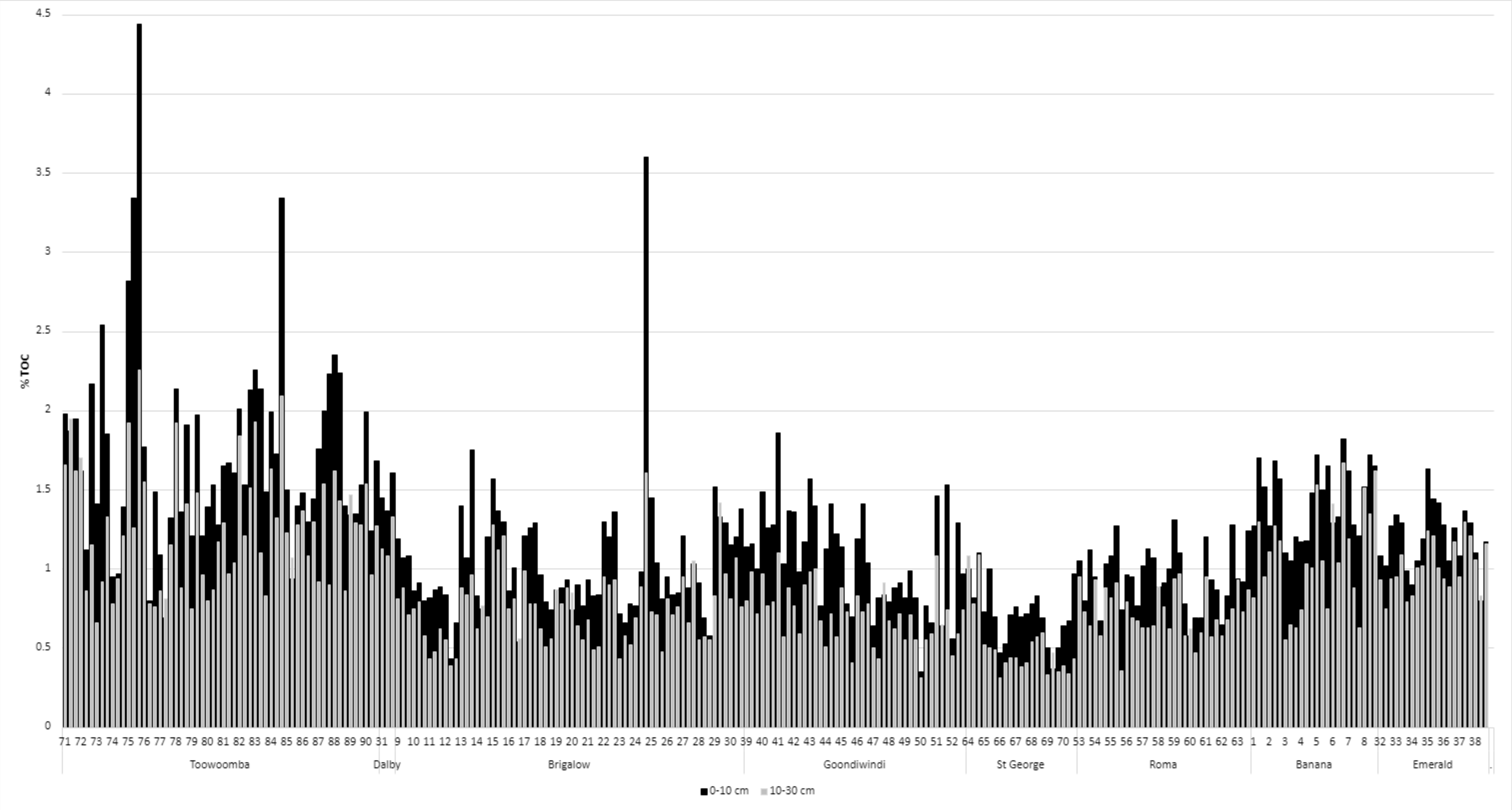

Figure 2. Total Organic Carbon (%): 0–10 cm and 10–30 cm for each paddock (listed 1 – 270) by location.

3. Colwell P levels (considered to indicate plant available phosphorus) were lowest in the Goondiwindi, Roma and St George regions and highest in the Toowoomba and Banana regions (Figure 3).

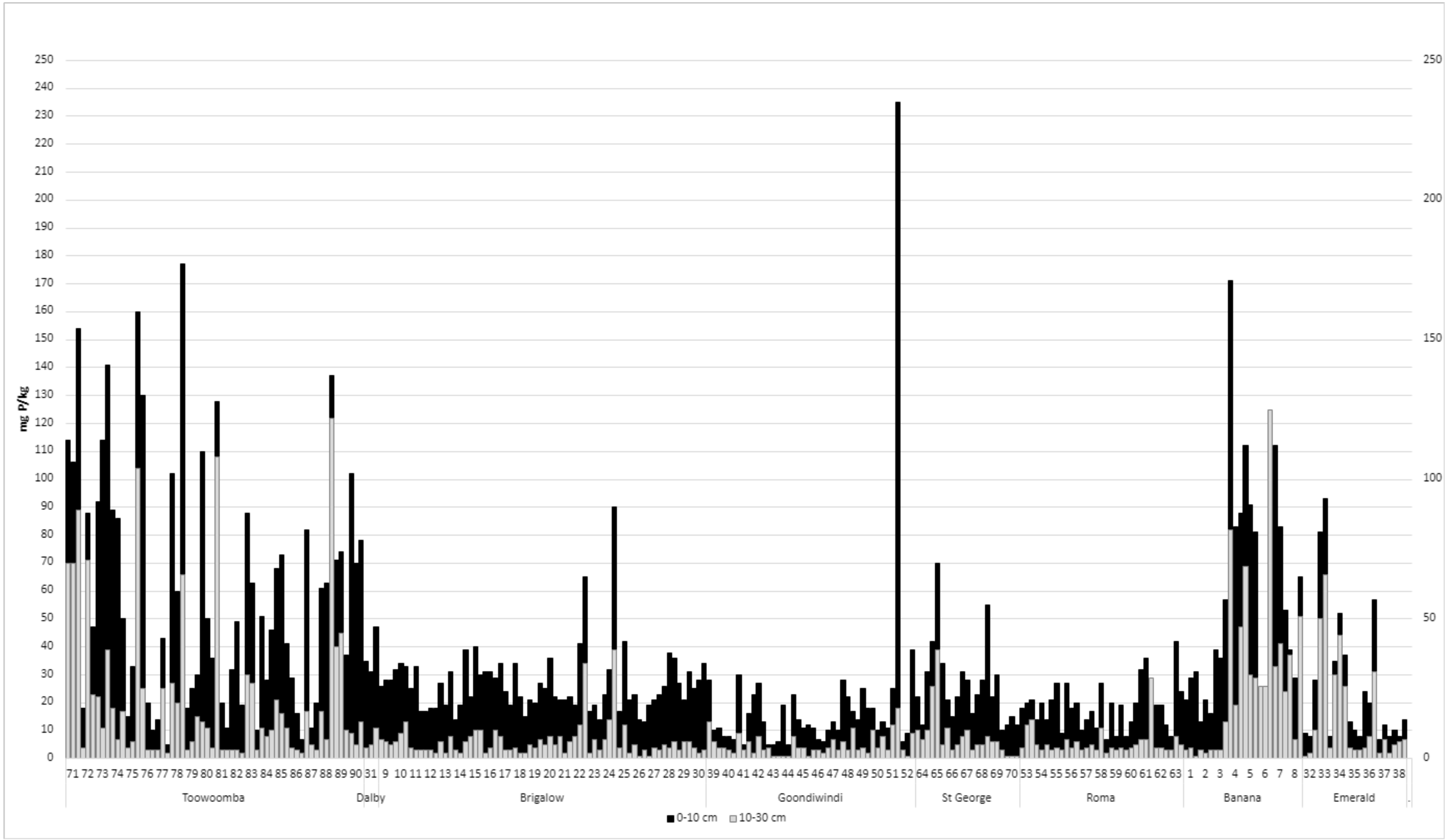

Figure 3. Colwell phosphorus (mg/kg): 0–10 cm and 10-30 cm for each paddock (listed 1–270) by location.

4. BSES phosphorus (considered to indicate P reserves that slowly become available) was considered low (< 50 mg P/kg in 10–30 cm layer) in 206 paddocks with the lowest levels detected in the Brigalow, Goondiwindi, St George and Roma regions (Figure 4). The lowest result was 5 mg P/kg in the 0–10 cm layer and <1 mg P/kg in the 10–30 cm layer. These are extremely low levels and will severely limit plant growth. Some paddocks had very high levels of BSES P due to their minerology.

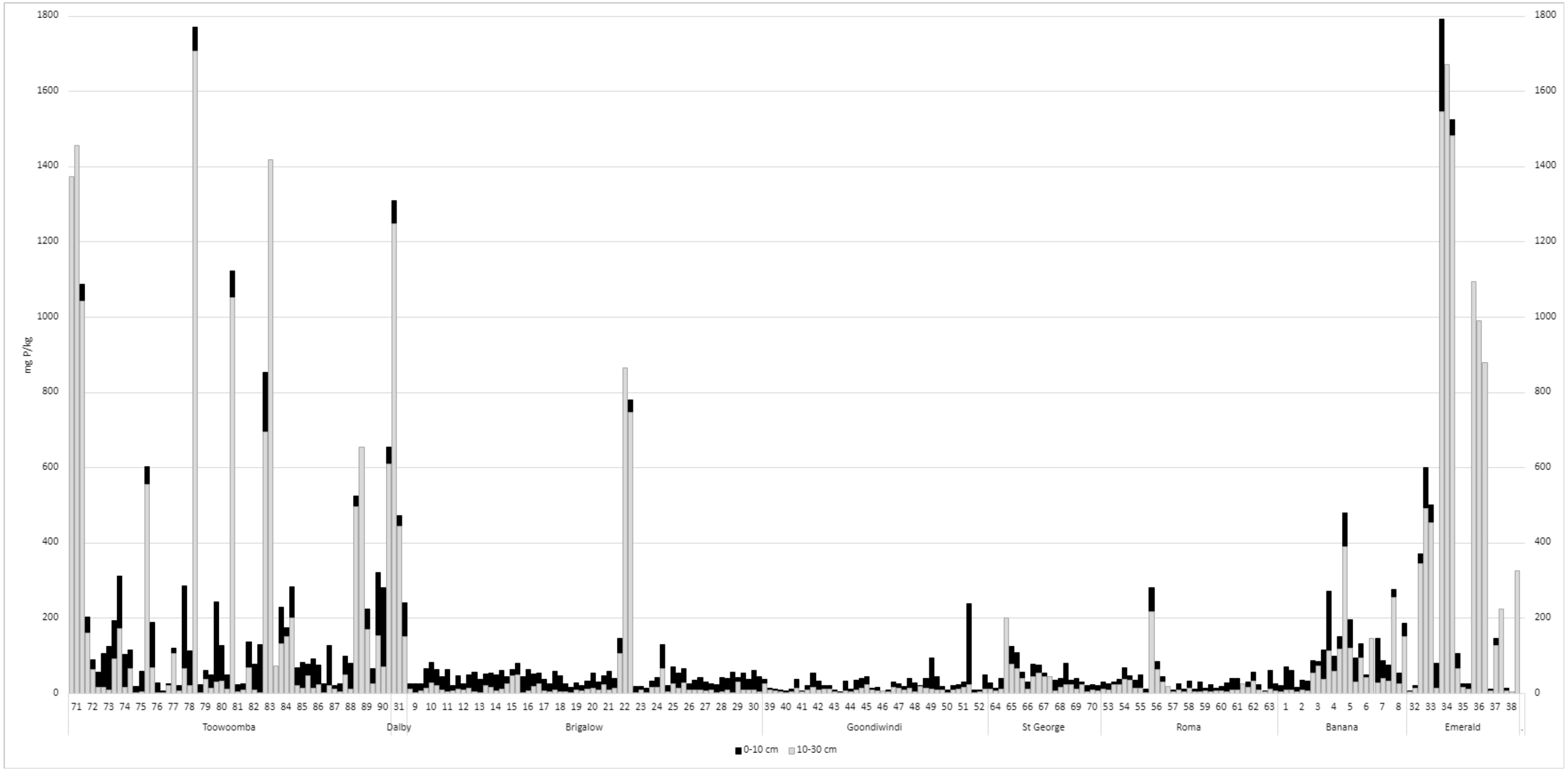

Figure 4. BSES phosphorus (mg/kg): 0–10 cm and 10-30 cm for each paddock (listed 1–270) by location

Responses to the application of deep P are likely if levels in the 10–30 cm layer are < 7 mg Colwell P/kg and < 50 mg BSES P/kg (Bell 2023). Of the 270 paddocks tested, 155 paddocks (57%) fell into this category.

5. Exchangeable K was observed to be consistently low in the Brigalow region and in some soils in the Goondiwindi region (Figure 5). Responses to the application of deep K are likely if levels in the 10–30 cm layer are: < 0.2 cmol K/kg for <10 cmol/kg cation exchange capacity (CEC); < 0.25 cmol K/kg for CEC 10–30 cmol/kg; and < 0.35 cmol K/kg for CEC >30 cmol/kg (Bell 2023). Of the 270 paddocks tested, 95 paddocks (35%) fell into this category.

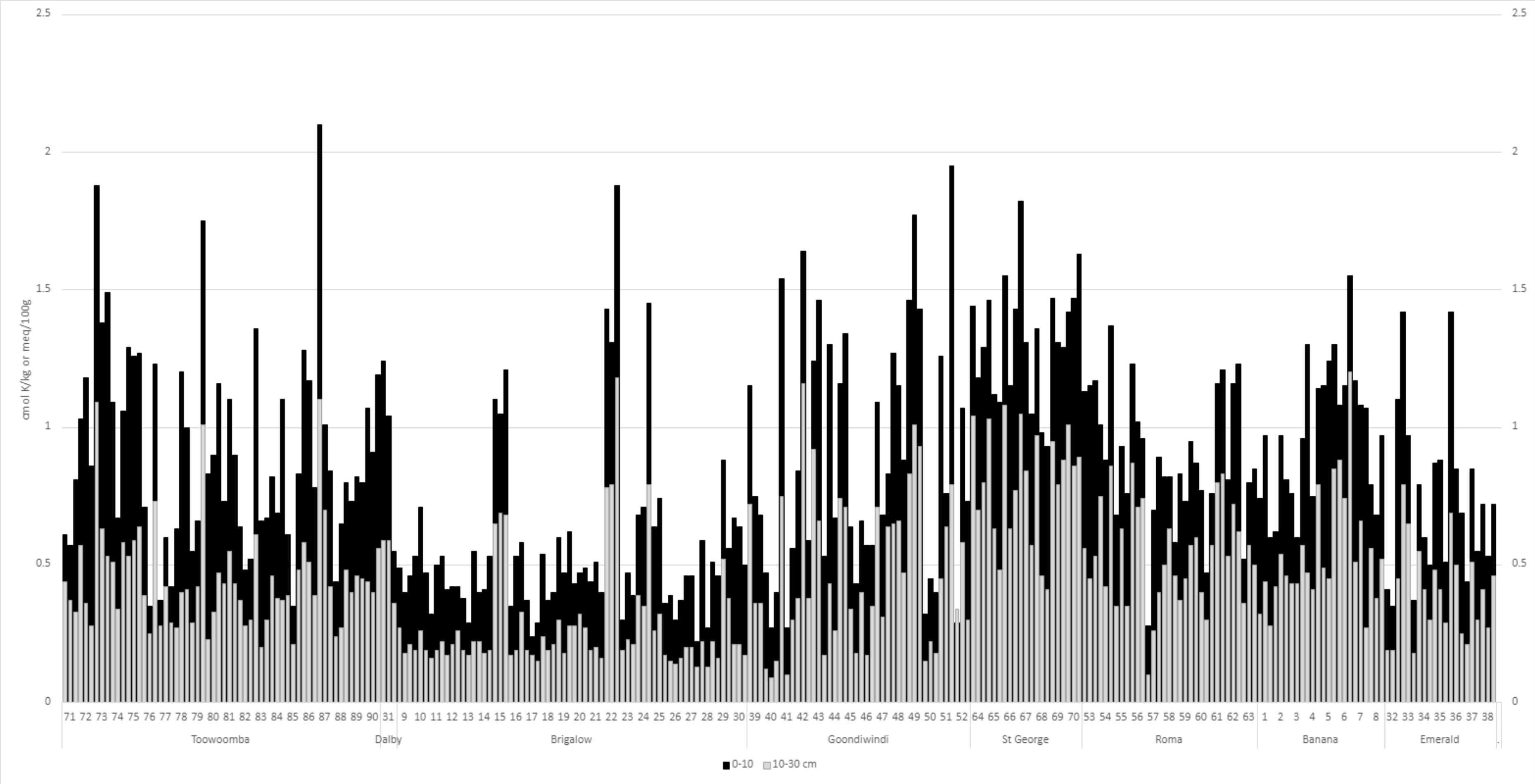

Figure 5. Exchangeable potassium (cmol K/kg): 0–10 cm and 10-30 cm for each paddock (listed 1 – 270) by location.

6. Salinity (measured as electrical conductivity $EC_{1:5}$, dS/m) increased down the profile, with moderate levels of salinity (>0.80 dS/m) often seen below 60 cm (data not shown). There were some very high levels (>1.5 dS/m) detected in the Roma region and to a lesser extent in the St George and Banana regions These very high levels may be limiting plant growth if correlated with high chloride.
7. Chloride levels were low for most paddocks (>150 mg/kg), with levels increasing down the profile. However, there were paddocks detected with chloride above 300 mg/kg below 30 cm in the Goondiwindi, St George, Roma and Banana regions (data not shown), which is considered to impair root growth of intolerant crops (e.g. pulses).
8. Sodicity was detected in many of the paddocks (measured as exchangeable sodium percentage (ESP) with levels increasing down the soil profile (data not shown). Soils are considered sodic when ESP is greater than 6%, with ESP greater than 15% indicating a strongly sodic soil. Sodic soils are often dispersive, which can reduce water infiltration and limit a plant's ability to extract water from soil. The Goondiwindi, St George and Brigalow regions had the highest ESP values. An ESP >15% was detected in 21% of paddocks (30-60 cm layer), 58% (60-90 cm) and 69% (90-120 cm).
9. Soil physical characteristics. The Emerson dispersion method showed poor structured (dispersive) soils occurred at varying rates across all geographical regions. St George, Goondiwindi and Brigalow had high rates of dispersive soil (58%, 54%, and 49% respectively) while Emerald was dominated by non-dispersive soils (94%) (data not shown). Dispersion was detected at different locations within the soil profile. As dispersion limits root growth, it was important to identify where the dispersion occurs in the profile to help understand the rooting depth of crops and from where soil water and nutrients can be accessed.
10. Soil biological data (measured via Predicta®B analysis, data not shown) indicated the most common pathogens to be those that cause crown rot, common root rot, white grain disorder, take-all, pythium root rot and charcoal rot. Interestingly, only 14 paddocks recorded levels over 2 *Pratylenchus thornei* g soil. Arbuscular mycorrhizal fungi (AMF) varied greatly across paddocks with <1 kcopies DNA/g soil being detected in five paddocks, through to the highest reading of 634 kcopies DNA/g soil.

One grower (Brigalow) was interested to compare their long-term cropping soil (50+ years) to bordering remnant vegetation to understand the change in soil health over time. Some very interesting results were observed:

- TOC: 0–10 cm was 0.77% in the cropping versus 3.6% in the remnant vegetation. This indicates a loss of ~3% TOC in the surface soil layer.
- Phosphorus: Colwell P levels decreased from 90 mg P/kg in remnant vegetation to 23 mg P/kg under cropping (0–10 cm layer); and from 39 to 7 mg P/ha (10–30 cm layer). The BSES P similarly declined from 131 to 33 mg P/kg (0–10 cm layer) and from 66 to 16 mg P/kg (10–30 cm layer).
- Chloride: levels significantly decreased under cropping, from 1674 mg/kg under remnant vegetation down to 13 mg/kg after 50+ years cropping (30–60 cm layer).

Implications for growers

Comprehensive soil testing and analysis is a useful tool to determine soil health. It is important to take deep cores and analyse them incrementally in line with dryland cropping critical levels. However, once a paddock has been tested and analysed, changes other than N and soil biology will be slow. Future testing may only be worthwhile every five to 10 years. Additionally, by comparing paddocks and considering their differences, a deeper understanding of how soil health is affected by different land use management practices can be gained.

Total organic carbon levels are quite low on Queensland cropping soils. This data set confirms past research findings that levels decrease when native vegetation is replaced by cropping. These lower levels reduce the overall resilience of soils, particularly the amount of N and P which can be mineralised and become available to support crop growth. This means that higher levels of fertiliser are required to continue to maximise crop production. To maintain carbon levels, growers need to boost biomass production, i.e. grow the biggest crops as often as possible. This can be achieved by implementing the best possible agronomy.

A large proportion of soils have low levels of immobile nutrients, such as P and K, that may be impacting crop production. Continuing to remove P and K from subsoil (i.e. 10–30 cm) layers without replacement will exacerbate this situation. Growers should consider replacing P and K in this subsoil when levels drop below critical levels. Past research shows that applying deep P fertiliser can be highly profitable in depleted soils. However, responses can vary. Further research is underway to assess the risk/reward trade-off with farm data. Potassium is a different story. There has been very little research focused on K to accurately determine critical levels and develop clear recommendations to rectify deficiencies. More research is required. Current recommendations suggest applying test strips to identify responses.

References

Bell, M. (2023). Fertiliser deep banding factsheet.
https://grdc.com.au/__data/assets/pdf_file/0027/590166/FertDeepBand_FS2023_screen.pdf

Dalal, R. C., & Mayer, R. J. (1986). Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. I. Overall changes in soil properties and trends in winter cereal yields. Soil Research, 24(2), 265-279.

Natural Resources Conservation Service. (2024). Natural Resources Conservation Service.
https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

Acknowledgements

The research presented within this paper would not have been possible without the support of growers and agronomists and investment from the Australian Government Landcare Fund and the Queensland Department of Agriculture and Fisheries.

This soil sampling was undertaken during the extraordinarily wet winter of 2022. It was all-hands -on-deck from the Regional Agronomy team to take advantage of the very small windows of ‘dry weather’ to take these soil cores. But the whole team’s perseverance and never-say-die attitude paid off. Not only did we get VERY good at taking soil cores from wet soil we have produced an exceptional dataset of grain cropping soils in Queensland. A big shout out to you all!

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The impact of long-term cropping on the storage and composition of soil organic carbon in Queensland Vertosols

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Key words

soil organic carbon, Vertosol, carbon forms, farming systems

GRDC code

UOQ1910-003RTX

Take home message

- Long-term cropping caused a marked loss of soil organic carbon (SOC) in all soil fractions
- SOC lost from each fraction differed by up to 53% but this was not associated with a change in SOC composition, indicating that the composition of SOC does not influence its stability
- Cropping impacts can be better managed by focussing on physical protection of SOC.

Introduction

Conversion of native land to agriculture drives the loss of soil organic carbon (SOC). Global anthropogenic driven losses within the last 12,000 years have been estimated at 116 billion tonnes of SOC in the surface 2 m of soil, although, most losses are predicted to have occurred within the last 200 years (Sanderman *et al.,* 2018). The loss of SOC can introduce limitations to agricultural productivity as SOC contributes positively to the water holding capacity, nutrient status and structural stability of Australia's agricultural soils (Murphy, 2015). Furthermore, loss of SOC contributes directly to greenhouse gas (GHG) emissions and thus also has implications for climate change (Kopittke *et al.,* 2021). Thus, there is a clear need to better understand the drivers of SOC persistence to better manage SOC stocks in our soil.

An emerging theory suggests that molecular diversity (composition) of carbon (C) exerts some control of SOC persistence (Lehmann *et al.,* 2020) as microbial decomposition of SOC can be hindered in environments with a larger range of organic compounds. This is because microbes require greater metabolic (energy) investments as the chemical diversity of organic compounds increases. Thus, once the most abundant C forms are consumed, the diversity of the remaining SOC increases, which subsequently reduces the rate of further decomposition (Lehmann *et al.,* 2020), potentially leading to increased retention of soil organic matter (SOM) (Jiménez-González *et al.,* 2018).

Within soil, there are different pools or fractions of SOM, of which SOC comprises approximately 58%. Briefly, these SOM fractions include the 'particulate organic matter' (POM), which is formed following the decomposition of plant materials such as retained stubble/crop residues. This POM can exist freely in the soil as free POM (fPOM) or can be physically protected through entrapment within aggregates, forming occluded POM (oPOM). In addition, there is the SOC which has become chemically bound to the fine inorganic minerals (such as clay-sized particles) in the soil, forming mineral associated organic matter (fine-MAOM, <53 µm size). It is beneficial for SOC studies to physically separate soil into these SOM pools to study them separately rather than solely investigating bulk SOC stocks (Angst *et al.,* 2023) as these fractions have different physical properties and are thus considered to play different roles in the soil C cycle. For example, POM fractions are generally more labile with higher proportions of plant-derived C. In contrast, MAOM can have a combination of plant- and microbial-derived C and are considered to have longer turnover periods (Cotrufo et al., 2019; Courtier-Murias et al., 2013; Kögel-Knabner et al., 2008).

This study investigated the composition of organic compounds in a series of cropped Vertosols from the Darling Downs region of southern Queensland, Australia (26.5°S and 28°S and 150°E to 152°E) to explore the role of SOC composition on SOC persistence. Soils were first fractionated into fPOM, oPOM and fine-MAOM to examine the impact of cropping on the contribution of these fractions to total SOC and the carbon stability within each fraction. We also assessed $\delta^{13}C$ values across the SOC fractions of each soil type. The $\delta^{13}C$ values of SOC can be used as an indicator for the degree of microbial decomposition as microbial processing of SOC results in ^{13}C enrichment of the remaining SOC ($\delta^{13}C$ values becomes less negative) as lower mass isotopes (^{12}C) are preferentially released as CO_2 during microbial respiration (Gunina & Kuzyakov, 2014). Finally, we assessed if the loss of SOC from each fraction was associated with a change in the composition of SOC organic compounds using synchrotron-based near edge X-ray absorption fine structure (NEXAFS) spectroscopy.

Characteristics of different organic carbon pools in soils with native vegetation

Within the soils with native vegetation (pre-land use change), most C was within the fine-MAOM fraction (7.5 – 14.7 g C kg soil^{-1}, Table 1) due to the high clay content in these Vertosols. The fPOM fraction was found to contribute the least to total SOC (1.3 – 3.4 g C kg soil^{-1}, Table 1). For all soils, C:N ratios of POM fractions were significantly higher ($p<0.05$) relative to the fine-MAOM fraction (Table 1). The $\delta^{13}C$ were specific to each soil type, however, within each soil $\delta^{13}C$ values generally increased from POM fractions to fine-MAOM. Significant differences ($p<0.05$) between $\delta^{13}C$ values of POM and the fine-MAOM fractions were only found in two of the four soils (Billa-Billa and Cecilvale). Lower C:N ratios and a greater ^{13}C enrichment observed in the fine-MAOM of each soil indicate a greater composition of microbial-processed SOC in fine-MAOM compared to the POM fractions (Cotrufo *et al.,* 2019; Gunina & Kuzyakov, 2014).

Table 1. Contribution of C, C:N ratios and $\delta^{13}C$ values for each SOM fraction of the native soils (pre-land use conversion).

Soil type	**Fraction**	**Contribution of C (g C kg soil^{-1})**	**C:N**	**$\delta^{13}C$**
Billa Billa	fPOM	3.4	17.8 ± 0.3^{a}	-23.7 ± 0.1^{a}
n=6	oPOM	5.5	18.8 ± 0.5^{a}	-23 ± 0.2^{a}
	Fine-MAOM	7.5	7.4 ± 0.2^{b}	-20.2 ± 0.4^{b}
Cecilvale	fPOM	2.3	26.5 ± 2.3^{a}	-18.9 ± 1^{ab}
n=7	oPOM	4.2	23.1 ± 0.9^{a}	-19.2 ± 0.4^{b}
	Fine-MAOM	10.6	9.6 ± 0.09^{b}	-15.7 ± 0.2^{c}
Langlands-Logie	fPOM	1.7	18.5 ± 1.4^{a}	-23.3 ± 2.3
n=4	oPOM	5.2	16.5 ± 0.7^{a}	-24.4 ± 1
	Fine-MAOM	12.1	7.8 ± 0.1^{b}	-21.6 ± 0.4
Waco	fPOM	1.3	23.9 ± 3.3^{a}	-16.8 ± 0.6
n=3	oPOM	1.1	19.7 ± 0.9^{ab}	-17.5 ± 0.6
	Fine-MAOM	14.7	7.9 ± 0.6^{c}	-15.2 ± 0.5

Effect of cropping on SOC stocks

After conversion to cropping, most changes in SOC concentrations occurred within the first 20 years of cropping (Figure 1). However, SOC retention differed substantially for each fraction. The fPOM fraction was found to be most sensitive to land use change, likely due to its lack of physical protection. In contrast, the fine-MAOM fraction displayed the most gradual change following conversion to cropping. From the regression, it was estimated that after 20 years of cropping, the fPOM fraction lost 78% of its SOC compared to native soils, the oPOM fraction had lost 59% and the fine-MAOM fraction had lost 25% (Figure 2). Thus, there was up to a 53% difference in SOC loss between fPOM, the most sensitive fraction, and fine-MAOM, the least sensitive. Despite the losses in SOC, C:N ratios and ^{13}C enrichment within each fraction generally remained stable for the cropping period investigated (data not presented). Although, the C:N ratios of the fPOM fraction of the Cecilvale and Waco soils, as well as the oPOM fractions of Cecilvale, Langlands-Logie and Waco soils did increase slightly with cropping (Figure 2). This is likely due to the incorporation of crop residues with higher C:N ratios relative to the original native vegetation (Bui & Henderson, 2013).

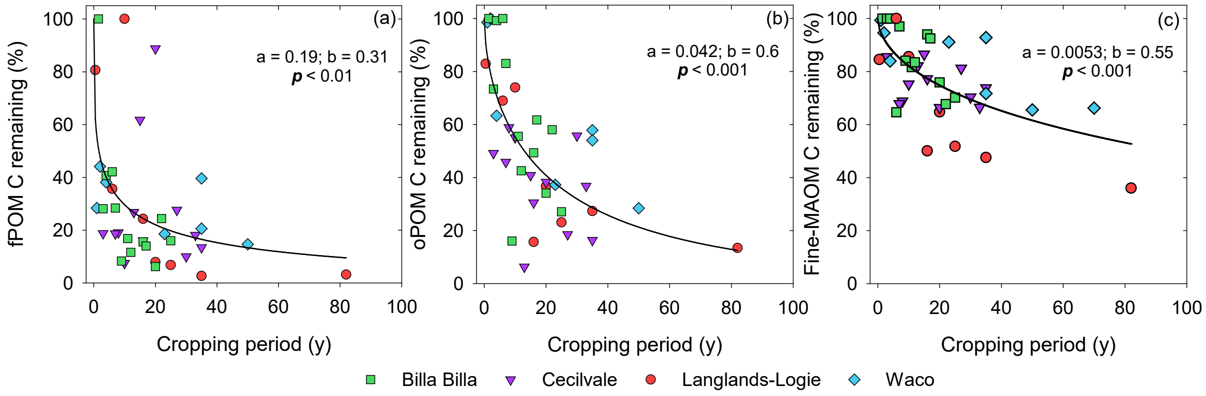

Figure 1. The C remaining in the (a) fPOM fraction, (b) oPOM fraction, and (c) fine-MAOM fraction compared to the native soils after cropping for up to 82 years. Decay modelled according to two-factor Weibull equation: Y(t) = 100/(exp((a.x)b)) where 'a' corresponds to the rate of decay and 'b' corresponds to the sigmoidal shape of the curve.

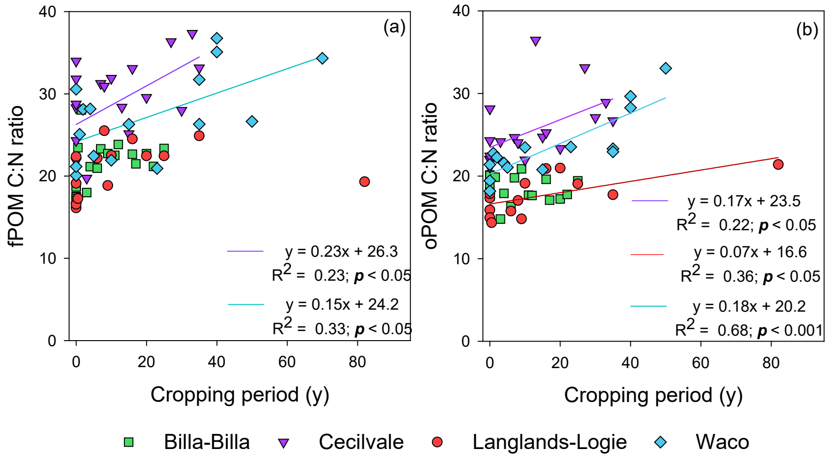

Figure 2. Changes observed in the C:N ratios of the fPOM and oPOM fractions during the cropping period investigated.

Effect of cropping on SOC chemistry

We then used NEXAFS spectroscopy to investigate SOC chemistry. We primarily assessed the changes to the composition of C forms as a result of land use change and/or microbial decomposition rather than attributing the different forms of C to their source of origin.

First, we assessed SOC composition between the different fractions of each soil type. NEXAFS spectroscopy revealed marked similarities across all three SOC fractions (Figure 3). It was estimated that across all samples (regardless of fraction or cropping history), carboxylic C (42.4 ± 0.6%), O-alkyl (25.7 ± 0.2%), and aliphatic C (21.3 ± 0.4%) were the dominant C forms. However, there were still some subtle differences between the fractions. For example, the oPOM fraction had the greatest composition of aliphatic C (for example, 23.1 ± 0.6% in the oPOM compared to 21.3 ± 0.8% in the fPOM fraction and 19.6 ± 0.4% in the fine-MAOM). Enrichment of aliphatic C within the oPOM fraction has previously been attributed to microbial processing as SOC transitions from fPOM to oPOM (Golchin et al., 1994; Mueller et al., 2009). In addition, the fine-MAOM had the highest composition of carboxylic C and O-alkyl C (for example, 45.2 ± 0.7% and 27.0 ± 0.1% compared to 38.9 ± 0.6% and 24.9 ± 0.2% in oPOM for carboxylic C and O-alkyl C, respectively). Carboxylic C and O-alkyl C are the most oxidised forms of C which reflects greater microbial processing of SOC within the fine-MAOM fraction (Kögel-Knabner et al., 2008; Lehmann et al., 2007). Therefore, these subtle differences in composition likely reflect an increasing degree of microbial processing between POM and fine-MAOM fractions (Golchin *et al.,* 1994; Kögel-Knabner *et al.,* 2008). This is also supported by the difference in C:N ratios and δ^{13}C values between POM and fine-MAOM fractions.

The effect of land use change on the SOC composition was then assessed by comparing the native (solid line) and cropped (dashed line) pairs (Figure 3). However, no pronounced differences between native and cropped sites were observed, indicating that long-term cropping did not have a pronounced effect on SOC composition, regardless of the fraction.

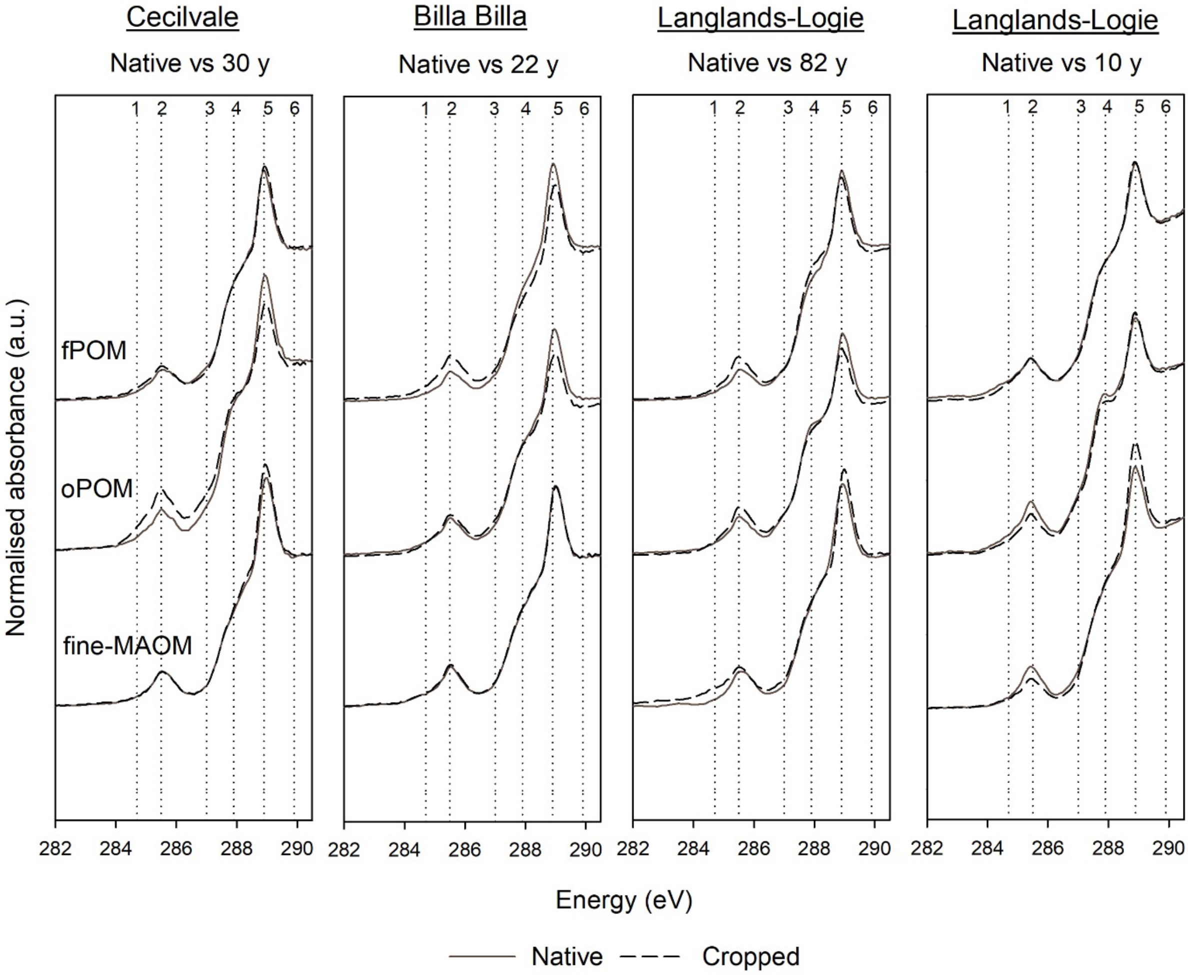

Figure 3. Spectra for selected native-cropped sample pairs comparing C functional groups across the fPOM, oPOM and fine-MAOM fractions in native and cropped (10–82 y) soil. The dotted vertical lines correspond to 1 = quinone C (284.7 eV), 2 =aromatic C (285.5 eV), 3 = phenolic C (287 eV), 4 = aliphatic C (287.9 eV), 5 = carboxylic C (288.9 eV), 6 = O-alkyl C (289.9 eV).

Implications of SOC persistence and stability

In the present study, two key findings were found regarding the role of SOC composition for SOC persistence after land use change. First, despite long-term cropping causing a substantial loss of C from all fractions, the SOC composition within each fraction remained almost unchanged between native soils and their cropped counterparts. This finding suggests that as SOC is lost from each fraction, there is a proportional loss of each form of SOC, i.e., there is no selective preservation of certain C forms over others (Dungait *et al.,* 2012). Secondly, although the amount of SOC lost in each fraction after land use change varied up to 53%, we found this did not translate to extensive differences in the SOC composition across the fractions. This finding suggests that the range in SOC loss between these fractions likely does not result from marked differences in SOC composition but rather from differences in the physical protection of the SOC through occlusion within aggregates or more importantly, through the formation of organo-mineral associations.

These findings suggest the impacts of cropping on SOC can be better managed by prioritising the physical protection of SOM (i.e. **minimising soil disturbance**) rather than efforts to change the chemistry of SOC. Furthermore, this information builds our understanding of C behaviour in soils, given that the role of SOC's complexity and diversity in SOC persistence after land use change remains unclear.

References

Angst G, Mueller KE, Castellano MJ, Vogel C, Wiesmeier M & Mueller CW (2023). Unlocking complex soil systems as carbon sinks: multi-pool management as the key. Nat Commun, 14(1), 2967. https://doi.org/10.1038/s41467-023-38700-5

Bui EN & Henderson BL (2013). C:N:P stoichiometry in Australian soils with respect to vegetation and environmental factors. Plant and Soil, 373(1/2), 553-568. http://www.jstor.org/stable/42952504

Cotrufo MF, Ranalli MG, Haddix ML, Six J & Lugato E (2019). Soil carbon storage informed by particulate and mineral-associated organic matter. Nature Geoscience, 12(12), 989-994. https://doi.org/10.1038/s41561-019-0484-6

Courtier-Murias, D., Simpson, A. J., Marzadori, C., Baldoni, G., Ciavatta, C., Fernández, J. M., López-de-Sá, E. G., & Plaza, C. (2013). Unraveling the long-term stabilization mechanisms of organic materials in soils by physical fractionation and NMR spectroscopy. *Agriculture, Ecosystems & Environment*, *171*, 9-18. https://doi.org/10.1016/j.agee.2013.03.010

Dungait JAJ, Hopkins DW, Gregory AS & Whitmore AP (2012). Soil organic matter turnover is governed by accessibility not recalcitrance. Global Change Biology, 18(6), 1781-1796. https://doi.org/10.1111/j.1365-2486.2012.02665.x

Golchin A, Oades JM, Skjemstad Jo & Clarke P (1994). Study of free and occluded particulate organic matter in soils by solid state 13C CP-MAS NMR spectroscopy and scanning electron microscopy. Australian Journal of Soil Research, 32(2), 285-309. https://doi.org/10.1071/SR9940285

Gunina A & Kuzyakov Y (2014). Pathways of litter C by formation of aggregates and SOM density fractions: Implications from 13C natural abundance. Soil Biology and Biochemistry, 71, 95-104. https://doi.org/10.1016/j.soilbio.2014.01.011

Jiménez-González MA, Álvarez AM, Hernández Z & Almendros G (2018). Soil carbon storage predicted from the diversity of pyrolytic alkanes. Biology and Fertility of Soils, 54(5), 617-629. https://doi.org/10.1007/s00374-018-1285-6

Kögel-Knabner I, Guggenberger G, Kleber M, Kandeler E, Kalbitz K, Scheu S, Eusterhues K & Leinweber P (2008). Organo-mineral associations in temperate soils: Integrating biology, mineralogy, and organic matter chemistry. Journal of Plant Nutrition and Soil Science, 171(1), 61-82. https://doi.org/10.1002/jpln.200700048

Kopittke PM, Menzies NW, Dalal RC, McKenna BA, Husted S, Wang P & Lombi E (2021). The role of soil in defining planetary boundaries and the safe operating space for humanity. Environ Int, 146, 106245. https://doi.org/10.1016/j.envint.2020.106245

Lehmann J, Hansel CM, Kaiser C, Kleber M, Maher K, Manzoni S, Nunan N, Reichstein M, Schimel JP, Torn MS, Wieder WR & Koegel-Knabner I (2020). Persistence of soil organic carbon caused by functional complexity. Nature Geoscience, 13(8), 529-534. https://doi.org/10.1038/s41561-020-0612-3

Lehmann, J., Kinyangi, J., & Solomon, D. (2007). Organic matter stabilization in soil microaggregates: implications from spatial heterogeneity of organic carbon contents and carbon forms. *Biogeochemistry*, *85*(1), 45-57. https://doi.org/10.1007/s10533-007-9105-3

Mueller, C. W., Brüggemann, N., Pritsch, K., Stoelken, G., Gayler, S., Winkler, J. B., & Kögel-Knabner, I. (2009). Initial differentiation of vertical soil organic matter distribution and composition under juvenile beech (Fagus sylvatica L.) trees. *Plant and Soil*, *323*(1-2), 111-123. https://doi.org/10.1007/s11104-009-9932-1

Murphy BW (2015). Impact of soil organic matter on soil properties: a review with emphasis on Australian soils. Soil Research, 53(6), 605-635. https://doi.org/10.1071/SR14246

Sanderman J, Hengl T & Fiske G J (2018). Correction for Sanderman et al., Soil carbon debt of 12,000 years of human land use. Proc Natl Acad Sci U S A, 115(7), E1700. https://doi.org/10.1073/pnas.1800925115

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. Part of this research was undertaken on the Soft X-ray spectroscopy beamline at the Australian Synchrotron, part of ANSTO (grant number AS233/SXR/20511). Tony King and Dr. Andrew Biggs from the Queensland Department of Resources are also gratefully acknowledged for their custodianship of the Vertosol soil series.

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Desiccating mungbeans – can we do better?

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Key words

mungbeans, desiccation, glyphosate

GRDC code

DAQ1806-003RTX

Take home message

- Growers can desiccate mungbeans for harvest either chemically or mechanically by windrowing
- Timing chemical desiccation is critical to minimise glyphosate residue levels
- Windrowing may be an option in the following situations: multiple flushes of pods, hard to kill vigorous mungbean plants, pending wet weather, heavy powdery mildew infestation, accessing markets with low glyphosate maximum residue levels and growing for seed &/or sprouting.

Background

Most Australian mungbean crops are chemically desiccated prior to harvest to aid 'dry-down' of the crop and facilitate mechanical harvest. Approximately 90 – 95% of the crop is desiccated with glyphosate, which is recommended for application when pods are black or brown (depending on individual product labels). Timing of desiccation is critical to ensure maximum dry-down whilst minimising chemical residue in the seed. Glyphosate is translocated through the plant. The target sites of glyphosate are the active meristems/apical parts of the plant. Glyphosate firstly moves to the tips of the leaves of penetration then it is loaded into the phloem and moves upwards to new shoots and buds. It then moves to the root tips. Death ultimately results from dehydration and desiccation. Translocation to immature seeds will result in detectable levels in these seeds which may have implications for marketing.

Improved mungbean varieties have led to more vigorous plants and desiccation has become increasingly problematic. One problem faced when harvesting mungbean is moisture remaining in the stem after desiccation. This stem sap can cause seed coat staining that results in downgraded grain quality. Consequently, growers have resorted to increasing rates of herbicides.

Export markets are becoming increasingly sensitive to pesticide maximum residue limits (MRL's) and the mungbean industry must be ready to adapt and meet market specifications if required. Furthermore, international markets are amending their MRL's in very short time frames – often too quickly for the industry to respond. Consequently, residues of glyphosate in mungbean are already affecting the acceptance of Australian mungbean in some export markets. With over 90% of Australian mungbean exported, alternative harvest practices that do not use crop protection products were deemed a priority in the current strategic plan of the national industry body, the Australian Mungbean Association (AMA).

The Mungbean Agronomy Project (DAQ1806-003RTX) led by the Queensland Government Department of Agriculture and Fisheries and supported by the Grains Research and Development Corporation and the Australian Mungbean Association undertook research to assess the potential of mechanical desiccation as an alternative to chemical desiccation of mungbeans. A series of large-scale commercial trials of mechanical desiccation (also known as swathing or windrowing) were implemented in 2022 following initial small plot experiments in 2021.

Windrowing is the mechanical process of swathing or cutting the crop to form the mungbean into a windrow on the ground. The windrow is harvested several days later by a header with a specialised pick-up front that lifts the crop off the ground. The 2021 trials successfully showed that mechanical desiccation of mungbean was a viable method. This report explores the results from the 2022 commercial scale trials.

What was done

2021

Four small plot trials were conducted, two at Emerald and two at Warwick, investigating rainfed and irrigated systems at each location. Eight treatments were assessed: control, mechanical desiccation at 30%, 60% and 90% physiological maturity (PM), glyphosate at the registered rate applied at 30%, 60% and 90% PM , and diquat applied at the registered rate at 90% PM. Harvest assessments were conducted at 3, 7, 10, 14 and 21 days after treatment (DAT). (For detailed information see: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/11/swathing-mungbeans-is-it-an-alternative-desiccation-method-in-mungbeans)

2022

Fifteen trials were implemented across southern Queensland and northern New South Wales. However, only 12 had complete data sets due to rain. (For detailed information see: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/desiccating-mungbeans-is-windrowing-an-alternative)

Two treatments were used in each trial: windrowing (Figure 1) and glyphosate (Figure 2) desiccation.

Figure 1. Windrowed mungbean

Figure 2. Chemically desiccated mungbean

Grain losses were measured using a variety of techniques at each stage of the treatments. Grain quality and glyphosate residue level in the seed (MRL) were also assessed.

Results

Grain quality

2021

Grain quality in 2021 commercial crops was generally low due to the high amount of late rainfall, with the quality of most crops falling into the manufacturing level. In the experiments, quality was lower for all treatments applied at both 30% and 60% PM. Mechanically desiccated mungbeans maintained a quality standard across harvest days (from day 3 to day 21). However, glyphosate treatments were downgraded if harvested too early (day 3) and too late (day 21) (data not shown).

2022

Mungbean grain quality was variable, however most trials achieved manufacturing grade and above (Figure 3, Table 1). Windrowed crops generally achieved higher quality levels (10 out of 15 had higher quality) than the chemically desiccated mungbeans including #14 where the glyphosate desiccated crop was abandoned due to excessive rainfall. These trials showed that moderate falls of rain from 25 to 50 mm on the windrowed treatments had no serious impact on mungbean quality and harvestability. Two crops had approximately 15 mm of rain (#01, #03) and in both cases the windrowed treatment had better quality mungbean than the traditional glyphosate treatment. However, an extreme weather event of over 100 mm for #02 resulted in the complete loss of the windrowed mungbean and severe quality downgrades for both treatments. In the cases of #13, #14 and #15, windrowing enabled the crop to be harvested before rain, due to quicker dry-down and no withholding period to observe, which resulted in a large quality advantage (Figure 3). Mungbeans deemed below manufacturing (BM) resulted from large amounts of rain (>100 mm) post desiccation.

Table1. Grain quality rating scale conversion table from commercial code to number code.

	Rating scale	No. rating scale
P=Processing	P1	9
	P2	8
	P3	7
M=Manufacturing	M1	6
	M2	5
	M3	4
BM = below manufacturing	BM1	3
	BM2	2
	BM3	1

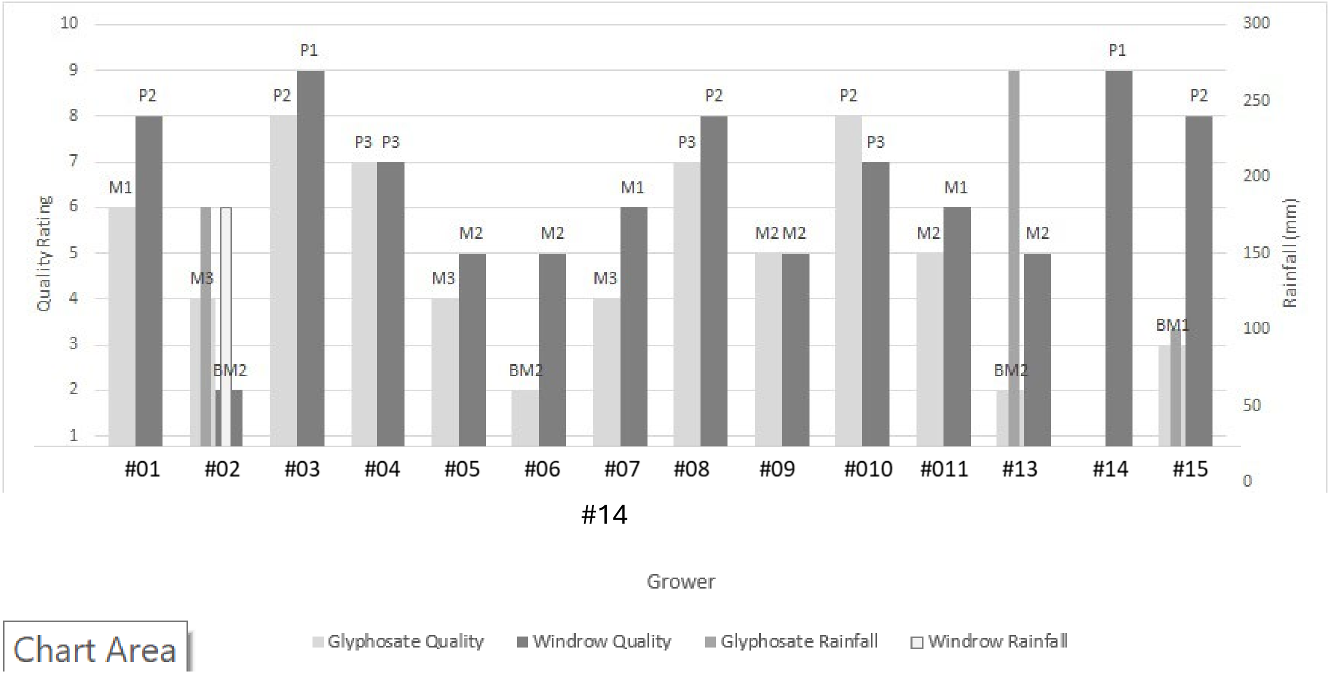

Figure 3. Grain quality for glyphosate and windrowed mungbeans and rainfall (ratings in Table 1)

*#14 glyphosate mungbeans were abandoned due to excessive rain (rainfall not recorded)

Glyphosate residue

The harvested seed in the glyphosate desiccated treatments was tested for glyphosate residue. All samples recorded glyphosate. The 2021 trial attempted to quantify the impact of 'spraying too early' i.e. at 30% PM and 60% PM. The data showed that the earlier mungbeans are sprayed the more residue is detected in the seed (Figure 4).

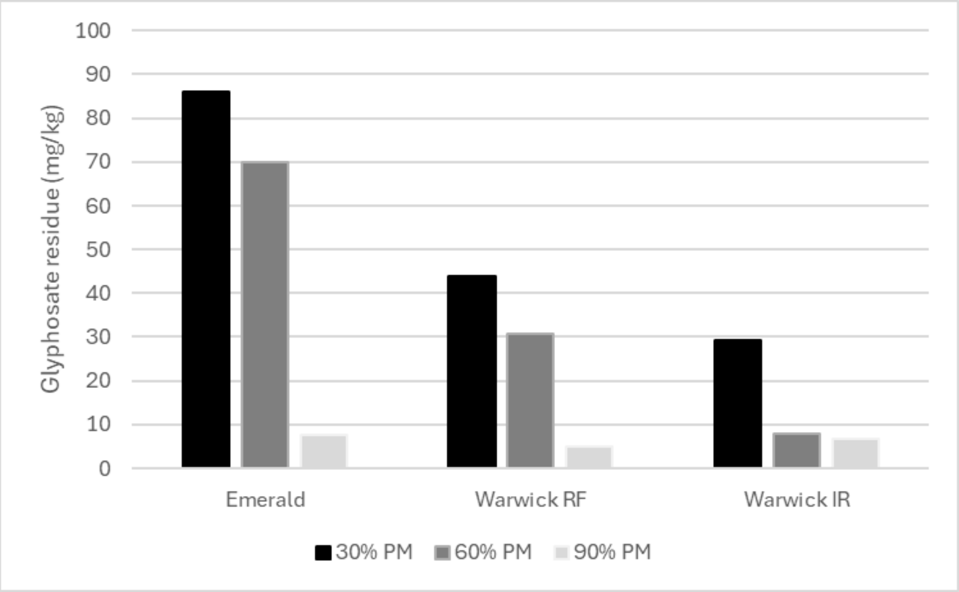

Figure 4. Glyphosate residue in seed @ 7 DAT at Emerald, and Warwick rainfed (RF) and irrigated (IR). Means with same subscript are not significantly different at the *P*=0.05 level.

In 2022, when all crops were chemically desiccated as per label (i.e. 90% PM), all samples were under the Australian maximum reside level (MRL) of 10 mg/kg (Figure 5). However, individual countries set their own MRLs. Taiwan currently has the lowest MRL of 2 mg/kg. Only two crops were over this MRL; #13 at 2.7 mg/kg and #08 at 5 mg/kg, which most likely had a higher percentage of green and immature pods at the time of glyphosate desiccation that resulted in translocation of the chemical into immature seeds.

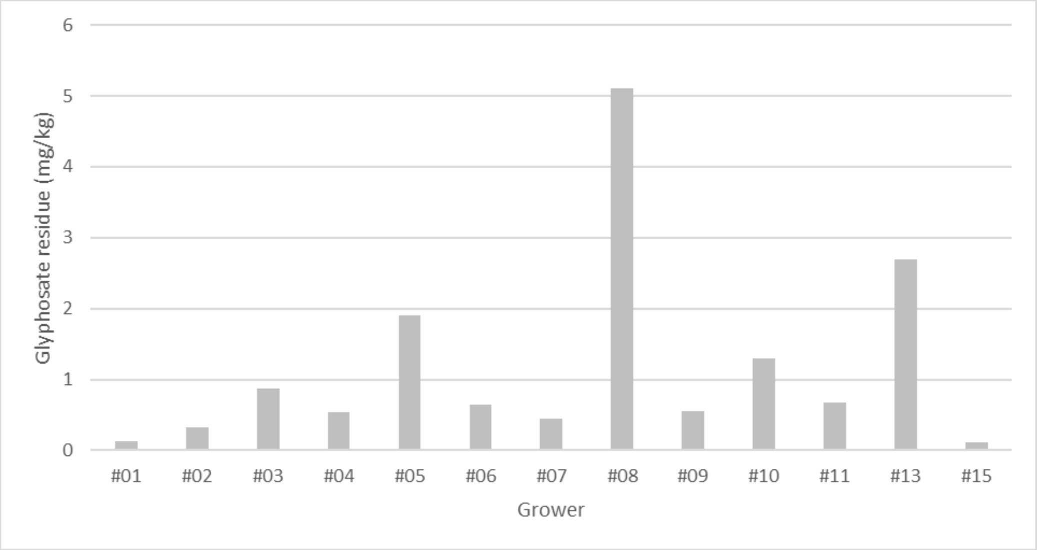

Figure 5. Glyphosate residue levels (mg/kg) of mungbean desiccated with glyphosate in 2022.

Implications to growers

Growers can choose to either chemically desiccate or mechanically desiccate (windrow) mungbean crops.

Mechanical desiccation

Mechanical desiccation may be an option in situations where:

- There are multiple flushes of pods
- Hard to kill vigorous mungbean plants are present
- Wet weather is forecast (i.e. in 7–14 days)
- Powdery mildew infestation is high and glyphosate can't be taken up by the plants
- The crop is destined for a market with low glyphosate MRLs (e.g. Taiwan)
- Crops that are targeting the seed &/or sprouting market. (Note: it is clearly stated on glyphosate label that it is NOT to be used for seed crops.)

Mechanical desiccation is not an option in situations where:

- Uneven ground is present (e.g., flood irrigated mungbean with large furrows) as this can result in very high losses.
- Very large amounts of rainfall are predicted
- Appropriate machinery is not available
- The soil is very wet (as this will result in wheel tracks and compaction).

Chemical desiccation

The key points when chemically desiccating mungbeans is the use of a robust label rate of desiccant and allowing sufficient time for the crop to dry down before commencing harvest.

Desiccating too early will result in spongy grain and seedcoat wrinkling, and therefore lower quality product. Spraying glyphosate prior to physiological maturity may result in translocation of the chemical to the seed. Ensure you discuss options with your marketer prior to desiccation and always read and follow product labels.

To minimise glyphosate seed residues:

- Accurately assess physiological maturity
- Do not desiccate immature crops

Timing of desiccant

Timing the application of a chemical desiccant is critical. An accurate assessment of the physiological maturity of the crop must be made. A crop must be desiccated once 90% of the pods have reached physiological maturity.

How to assess physiological maturity:

- Assess pod colour – yellow through to black pods generally have reached maturity.
- Assess seeds in the pod – mature seeds will fall out of the pod. Split the pod longways and tip the pod upside down. Mature seeds will fall from the pod.
- Assess in multiple locations within the paddock

Mechanical desiccation

Mechanical desiccation (windrowing) of mungbeans is a new harvest option and has not been trialled extensively. However, initial research has shown it is a viable option.

The key points when windrowing mungbeans is timing, both the cutting and harvesting. Desiccating too early, similar to chemical desiccation, will result in seedcoat wrinkling, and therefore lower quality product. Desiccating too late will result in larger harvest losses. Dry-down time will be faster than chemical desiccation and significant losses can be recorded if pick-up of the crop is too late.

Timing of mechanical desiccation

Timing mechanical desiccation it not as critical as it is for chemical desiccation as there is no risk of chemical translocation. The crop should be desiccated when 90% of the pods have reached physiological maturity.

Pick-up from the windrows can occur as soon as the crop is sufficiently dry to thresh; normally 5–7 days but this is weather dependant. For example, it may be as fast as 3 days after desiccation under hot, dry conditions and as long as 14 days under mild, wet conditions.

Harvest losses may be reduced by picking-up early in the morning whilst there is still moisture on the crop. If the crop is too dry harvest losses can be significant.

Once the mungbean crop has been mechanically desiccated and put into a windrow, it can tolerate small amounts of rain (i.e. up to ~50mm). However, large amounts of rain and very wet ground can result in mould and reduction in yield and quality.

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 (DAQ1806-003RTX). The author would like to thank them for their continued support. Further thanks to the Australian Mungbean Association for both their funding and support of this research. Finally, this research would not be possible without a team of dedicated research and technical staff.

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Fall armyworm impacts & thresholds in sorghum & maize - management options & guidance for 2024/25

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Improving grain grower business resilience before, during and post drought – ARM Online tools to assist on-farm decision making

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Key words

drought resilience, decision-support tools, crop rotations, ARM Online

Take home message

The Agricultural Risk Management (ARM) Online platform (www.armonline.com.au) provides growers and agronomists with digital tools that evaluate the drought resilience of alternative cropping strategies. The platform assists in choosing cropping systems that have both a high level of drought resilience and perform well across further target indicators, such as profitability. Recently, new functionality has been added to the CropARM decision-support tool that focuses on optimising tactical crop management decisions. Furthermore, the new RotationARM tool has been developed to assist in selecting resilient cropping systems. Over the coming months, a series of capacity-building workshops are being delivered to guide growers and their advisors in using these tools to build their drought resilience. Participants will learn to analyse their cropping systems and develop and refine their own rules of thumb.

Introduction

Drought is characterised by abnormally dry conditions when the amount of water available is not enough to meet the typical usage across the community and environment (BOM 2019). Agriculture is the first sector affected by drought and is the most severely affected part of the economy. It absorbs 80% of the direct impacts of drought exposure (FAO 2023). Not only does production decrease but food security and the livelihoods of those who live and work in rural communities are also negatively impacted. Weather and climate risks have always been present in Australian agriculture and Australian farmers are continuously developing new ways to managing these risks in their business operations. However, drought remains a persistent and challenging risk for dryland grain growers. Since droughts are an enduring part of the Australian landscape and are difficult to predict, they must be mitigated through proactive preparation that builds resilience into farming systems. Resilience means that a system can absorb shocks and is capable of regenerating after the disturbance. Drought result in significant personal and communal hardship. Therefore, growers and government are continuously seeking ways of managing these risks from both operational and financial perspectives.

Personalised decision-support tools with the capability to bench test alternative cropping scenarios can enable growers to develop resilient cropping systems well before the next drought. In this project, we have updated and added functionalities for drought analysis into the CropARM tool and have created a new tool called Rotation Agricultural Risk Management (RotationARM) that allows growers to analyse current and potential cropping systems across a range of performance metrics. These tools are part of the ARM Online platform (https://www.armonline.com.au/) and use the APSIM Next Generation cropping systems model (Holzworth *et al*. 2018) as their engine. This puts the collective knowledge from over 60 years of research on how crops grow and interact with the environment (Keating 2024) into the hands of growers and advisors via a user-friendly interface.

Optimising crop management in CropARM

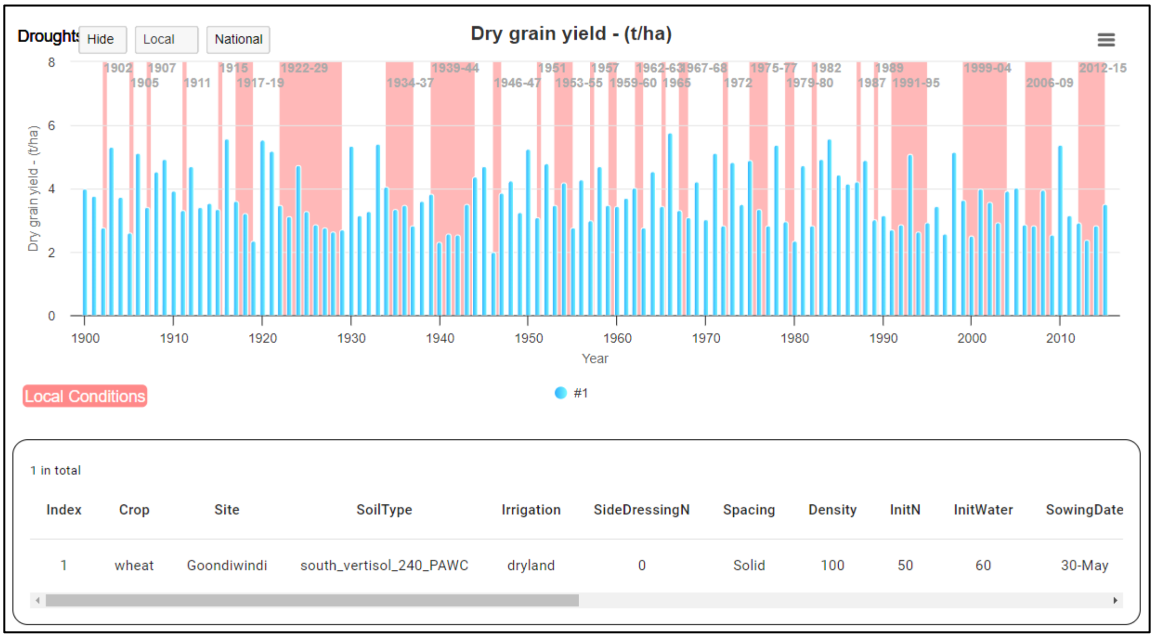
CropARM is an online version of the WhopperCropper tool (Cox *et al.,* 2004). It enables users to analyse the impact of cropping decisions such as sowing date, plant density, cultivar choice and nitrogen fertiliser rate on their local soil and climatic conditions. It presents results through a series of graphics enabling users to compare crop management options and identify the best management choices for their risk preferences and long-term objectives.

New functionality has been implemented into CropARM enabling users to assess the impacts of local and national droughts on their crop performance. The user performs the analysis in CropARM by specifying their crop management. Once they inspect the overall results, they can overlay the analysis with drought conditions with the option to select:

- specific local droughts (based on the ratio of rainfall to potential evapotranspiration; Dalezios *et al.,* 2017) or
- nationally recognised droughts (defined by BOM 2020).

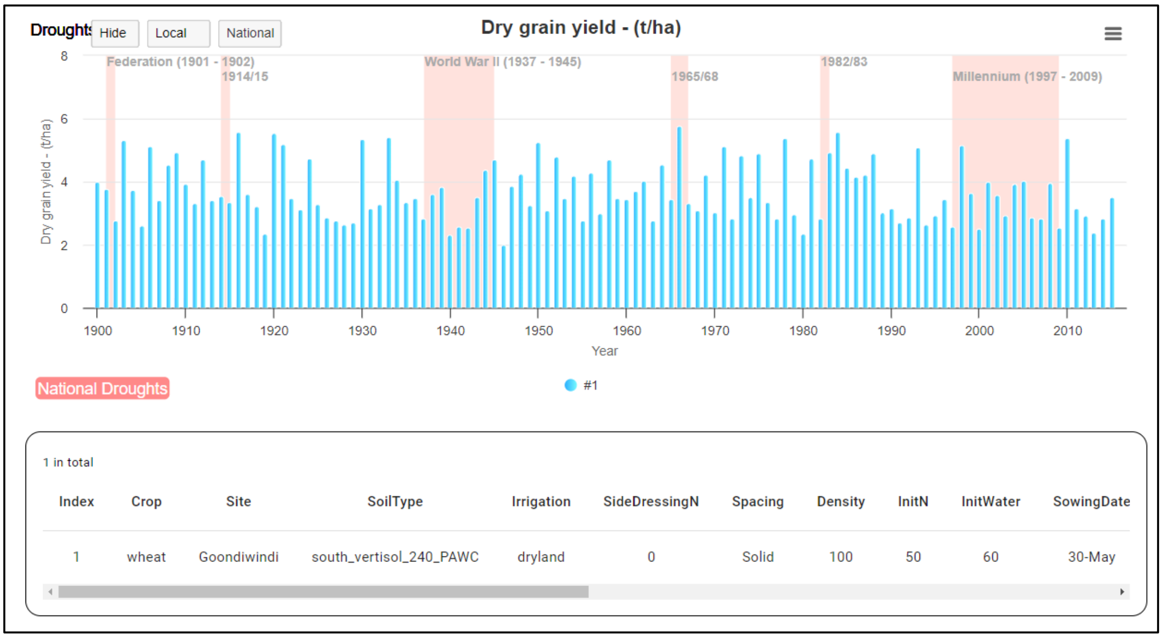
Figure 1 shows an analysis of wheat grown at Goondiwindi. The top figure highlights the years when Goondiwindi experienced drought conditions (indicated by the shaded background). The bottom figure shows the major nation-wide droughts. The impact of prolonged drought on crop yields can be clearly seen and can differ between the local and nationally recognised droughts.

One potential strategy for building drought resilience is to adopt less commonly cultivated crops. As CropARM uses APSIM as its analytical engine, only the specific crops included in the model are available for analysis. To allow an analysis of additional crop options that are not yet available in APSIM a new method to statistically simulate seasonal crop yields has been implemented into CropARM. This method is based on an adjusted triangular distribution function and simply requires the user to define the crops growing season, as well as the minimum, maximum and average expected yield. Figure 2 demonstrates this analysis in combination with the drought analysis for pigeon pea grown at Goondiwindi (values for demonstrative purposes only).



1 in total

Index	Crop	Site	SoilType	Irrigation	SideDressingN	Spacing	Density	InitN	InitWater	SowingDate
1	wheat	Goondiwindi	south_vertisol_240_PAWC	dryland	0	Solid	100	50	60	30-May



1 in total

Index	Crop	Site	SoilType	Irrigation	SideDressingN	Spacing	Density	InitN	InitWater	SowingDate
1	wheat	Goondiwindi	south_vertisol_240_PAWC	dryland	0	Solid	100	50	60	30-May

Figure 1. A local and national drought analysis performed in CropARM for wheat grown at Goondiwindi. The top panel shows the analysis overlayed with local drought conditions (shaded), while the lower panel shows the analysis overlayed with national drought conditions (shaded).

Triangular Distribution Parameters

This type of scenario uses historical seasonal results to predict the likely result of other seasonal crops for which there are no simulation data.

Note: The inclusion of a Triangular Distribution will restrict results to only show yield data.

Min. Yield * 0

Max. Yield * 4

Expected Yield * 2.5

Crop Type: ● Summer ○ Winter

Description/Crop Name * Pigeon pea

View Type: Bar Chart

1 in total

Index	Crop	Site	SoilType	minYield	maxYield	expYield	season	description	mean	10_percent_
1	Pigeon Pea	Goondiwindi	south_vertisol_240_PAWC	0	4	2.5	summer	Pigeon Pea	2.4	1.3

Figure 2. An analysis of pigeon pea grown at Goondiwindi using statistically derived crop yield in combination with the drought analysis functionality in CropARM.

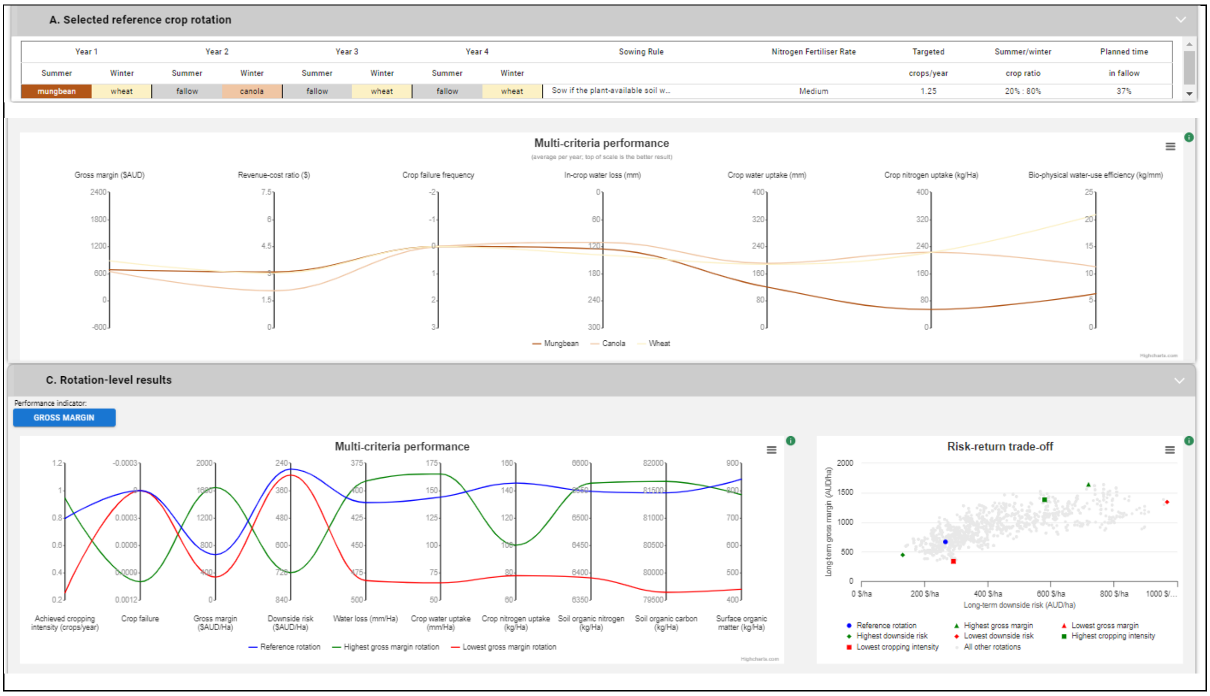
Optimising the overall cropping system in RotationARM – a new tool

A key part of preparing for drought is setting up the cropping system for increased resilience. Rotation Agricultural Risk Management (RotationARM) has been developed to enable the analysis at a whole system level that considers the interactions between subsequent cropping decisions. Users specify their location, production costs, prices, crops grown, the cropping intensity (crops/year), production inputs and sowing rules. The tool then presents results for key system performance metrics (Figure 3) such as overall gross margin, achieved cropping intensity, water use efficiency, soil carbon levels and surface organic matter cover. Further analysis can be undertaken to compare different systems and intensities under different drought exposure scenarios, allowing the user to identify the system that best meets their objectives in a drought-resilient manner.

Building drought resilience within the broadacre cropping sector

These tools are designed to help growers identify system-level options and create or refine cropping decision rules of thumb. To facilitate the use of these tools a series of one-day workshops (Zull *et al.*, 2024) are being delivered across Queensland and northern New South Wales in the coming months. These workshops will enable growers and advisors to:

- Identify tactical crop management decisions that improve resilience during drought exposure
- Compare strategic choices between different crop rotations to increase drought resilience as part of preseason planning
- Develop personal learnings and rules-of-thumb (improve drought resilience)
- Understand how to improve drought resilience into the future (continued improvement).



A. Selected reference crop rotation

Year 1		Year 2		Year 3		Year 4		Sowing Rule	Nitrogen Fertiliser Rate	Targeted	Summer/winter	Planned time
Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter			crops/year	crop ratio	in fallow
mungbean	wheat	fallow	canola	fallow	wheat	fallow	wheat	Sow if the plant-available soil w...	Medium	1.25	20% : 80%	37%

Figure 3. The results of an analysis of a wheat-canola-mungbean cropping systems at Goondiwindi in RotationARM.

References

BOM (2019) Australian Government, Bureau of Meteorology: Explainer - what is drought? Retrieved 6/10/23, from https://media.bom.gov.au/social/blog/2179/explainer-what-is-drought/

BOM (2020) Special Climate Statement 70 update—drought conditions in Australia and impact on resources in the Murray–Darling Basin, Bureau of Meteorology Canberra

Cox HW, Hammer G, McLean GB & King C (2004) September. National Whopper Cropper—risk management discussion support software. In Proceedings of the 4th International Crop Science Congress.

FAO (2023) Land and Water (Drought). Retrieved 6 Oct 2023 https://www.fao.org/land-water/water/drought/en/

Holzworth D, Huth NI, Fainges J, Brown H, Zurcher E, Cichota R, Verrall S, Herrmann NI, Zheng B & Snow V (2018) APSIM Next Generation: Overcoming challenges in modernising a farming systems model. Environmental Modelling & Software, 103, 43-51.

Keating BA (2024) APSIM's origins and the forces shaping its first 30 years of evolution: A review and reflections. Agronomy for Sustainable Development 44.

Dalezios, NR, Dunkel, Z & Eslamian, S (2017). Meteorological Drought Indices: Definitions. In Handbook of Drought and Water Scarcity. CRC Press. https://doi.org/10.1201/9781315404219-3

Zull A, Grewer U, Anderson R & Pembleton K (2024) Personalised Cropping Decisions – Preparation, Management, and Recovery from Drought. Workshop Manual. Toowoomba, Qld: University of Southern Queensland and Department of Agriculture and Fisheries.

Acknowledgements

This project is jointly funded through the Australian Government's Future Drought Fund's Drought Resilience Innovation grants program, the University of Southern Queensland, and the Queensland Government Department of Agriculture and Fisheries.

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Greenhouse gas footprint of different farming systems in the northern grains region

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Keywords

emissions intensity, crop rotation, nitrogen, emissions reductions, greenhouse gas

GRDC code

DAQ2007-004RMX

Take home messages

- Modelled greenhouse gas (GHG) emissions were dominated by soil nitrous oxide (N_2O) losses (>50% of total); Scope 3 (pre-farm gate) emissions were typically <20% of total emissions
- Accounting for changes in soil carbon significantly altered GHG footprint across sites and systems, contributing to, or mitigating, their GHG footprint
- There was up to a twofold difference in total GHG emissions between the highest and lowest emitting cropping systems at each site
- Despite higher inputs, *Higher intensity* cropping systems generated lower total emissions; drier soils and reduced time in fallow limited N_2O losses, and increased biomass inputs improved the soil C balance compared to other systems. In contrast, *Low intensity* systems showed higher total emissions
- *Higher nutrient* input strategies led to higher emissions due to increased N_2O losses, as well as higher emissions associated with fertiliser production and use
- Changing the mix of crops by employing *Higher legume* frequencies or *Higher diversity* systems did not show a consistent effect on total emissions (ranging from 700 kg CO_2-eq/ha/yr lower to 450 kg CO_2-eq/ha/yr higher); differences were site specific.

Introduction

Reducing greenhouse gas (GHG) emissions is crucial for the environmental standing and global market access of Australia's agricultural sector. Identifying and implementing practices that reduce emissions or optimise GHG intensity (maximise productivity per unit of GHG emitted) is a key priority of the Australian grain industry. While national studies have been conducted to assess GHG footprints and mitigation options (see Grains Research and Development Corporation (GRDC)'s Emissions Factsheet), the implications of local practices remains unclear. A localised approach is necessary to provide detailed insights and verify assumptions from broader assessments.

Farming systems experiments funded by GRDC offer a comprehensive dataset for evaluating the GHG impacts of different farming methods across the northern grain regions of New South Wales and Queensland. This dataset spans several years and includes multiple system variations, such as: increasing crop diversity (including legume frequency and alternative crops); altering cropping intensity (balance between fallow and active growth phases);

strategies that influence fertiliser and chemical inputs; and the incorporation of regenerative practices such as ley pastures or cover crops. Each of these factors influence soil carbon (C) and nitrogen (N) balances, as well as input requirements. Consequently, this study aims to assess the potential of a diverse range of farming systems to mitigate or lower GHG emissions and intensity.

What we did

Farming systems experiments

Farming systems experiments have been underway at seven locations in central and southeast Queensland and northern New South Wales since 2015. These experiments capture data crucial for estimating GHG emissions and intensity (i.e. GHG per tonne of grain/product), including variables like crop biomass and grain yield, fertiliser and chemical inputs, and operations such as sowing, harvesting, and spraying. Due to intricacies and ambiguities in attributing emissions from livestock grazing, systems that incorporate rotations with ley pastures have been omitted from this analysis (but are likely to be done in the future). As a result, this report focusses on grain-exclusive production systems.

The dataset comprises over 80 combinations of farming system treatments across 7 sites spanning eight years (March 2015 – April 2022). Each site features a *Baseline* system, embodying the prevailing understanding of a best-practice crop sequencing and management of the respective cropping region. Alternative systems modify the *Baseline* sequence in several ways: *Higher/lower crop intensity* – widening sowing windows and altering the soil water threshold to trigger sowing a crop and thus increasing/decreasing the proportion of time when crops are growing; *Higher legume* – incorporating at least 50% grain legume crops; *Higher diversity* – increasing the range of crops available for use (e.g. canola, cotton) and forcing a two-break crop requirement before the same crop can be grown again; and *Higher nutrient* supply systems, which increase the annual nitrogen and phosphorus budget from a median crop yield (Decile 5) to a higher yield expectation (Decile 9). At most sites, individual treatments are applied, whereas combinations of these strategies are evaluated in the core experiment at Pampas on the Eastern Darling Downs.

Calculating GHG emissions

Drawing from farming systems experimental data, we employed a Tier 3 (i.e. locally specified calculations or modelling) approach to estimate GHG emissions over the experimental period (2015–2022). This differs from Tier 2 or Tier 1 approaches that use national or international emissions factors to estimate emissions using regional activity data. Emissions are separated into Scope 1 (on-farm), Scope 2 (associated with electricity use on farm) and Scope 3 (pre-farm gate emissions embedded in farm inputs like fertilisers and pesticides). Scope 2 emissions were negligible (<1% of total) and thus not included in this analysis. Scope 1 emissions occurring on-farm include sources such as N_2O emissions from the soil (including from decomposition of crop residues), and CO_2 emissions from diesel used by on-farm machinery and hydrolysis of urea fertilisers. Using activity data for each site and system we simulated experimental management in APSIM to predict direct N_2O emissions (i.e. from the soil), indirect N_2O emissions (i.e. from N lost in runoff or leaching) and changes in soil C over the experimental period (Figure 1). Other emissions sources were estimated using emissions factors defined in the National Greenhouse Gas Inventory (NGGI) 2021 (National Inventory Report, 2023).

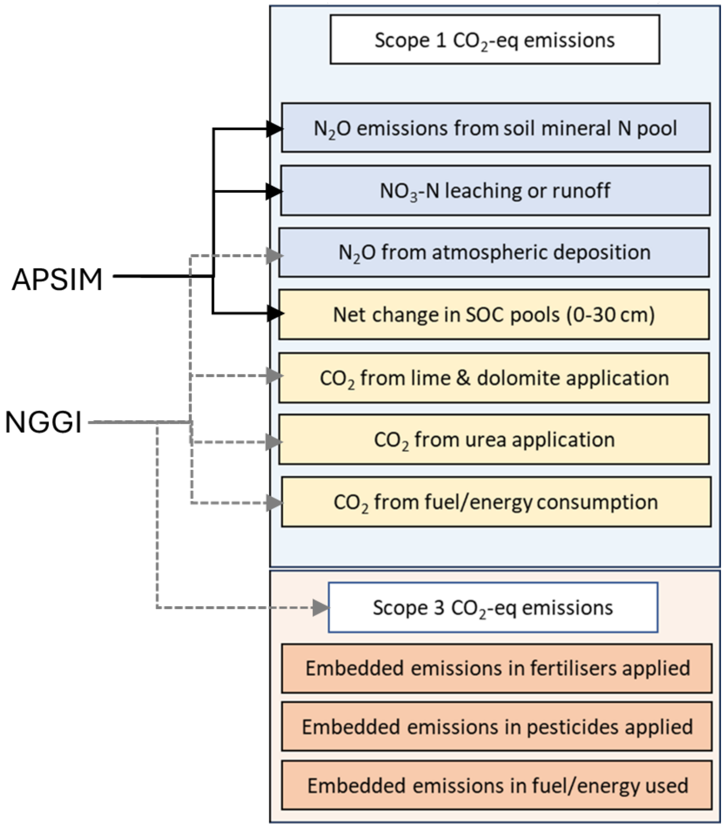

Figure 1. Various GHG sources calculated using activity data from farming systems experiments and those that were estimated from simulations using APSIM and those that used the National Inventory Report (2021) values.

After compiling total GHG emissions from the various sources, we calculated the emissions intensity for each system, defined as the gross margin per kilogram of CO_2 emitted. While other analyses might measure emissions intensity per tonne of grain, this approach does not provide a fair comparison among systems due to variations in yield and values of different crop types that make up these systems. This metric also aids in estimating potential abatement costs, that is, cost to implement a system that reduces net emissions. However, our calculations are based on assumptions about crop prices and inputs, making these figures specific to certain seasons and conditions and not universally applicable.

Emissions sources from farming systems

Without considering soil C change, other emissions sources were estimated to average 830 kg CO_2-eq/ha/yr and vary amongst sites between 650 to 1400 kg CO_2-eq/ha/yr for the *Baseline* systems, except Mungindi which has a drier climate and hence was significantly lower (330 kg CO_2-eq/ha/yr).

Across all sites, emissions associated with direct N_2O losses from the soil were the largest contributor to the GHG footprint of the farming system (Figure 2). While N_2O losses are small, they have a large relative global warming potential, with each kg of N_2O has an impact equivalent to 298 kg of CO_2. It is worth noting that this estimated N_2O emission includes emissions coming from both fertilisers applied as well as from N mineralised from soil organic matter (discussed below). Scope 3 emissions associated with inputs of fuel, fertiliser and pesticides were typically less than 20% of the total emissions at all sites, but the relative contribution of each varied across sites depending on the relative use of these inputs (Figure 2).

There was large variability in the estimated change in soil C between sites, but on average the soil C decline was estimated to contribute 25% of the total emissions.

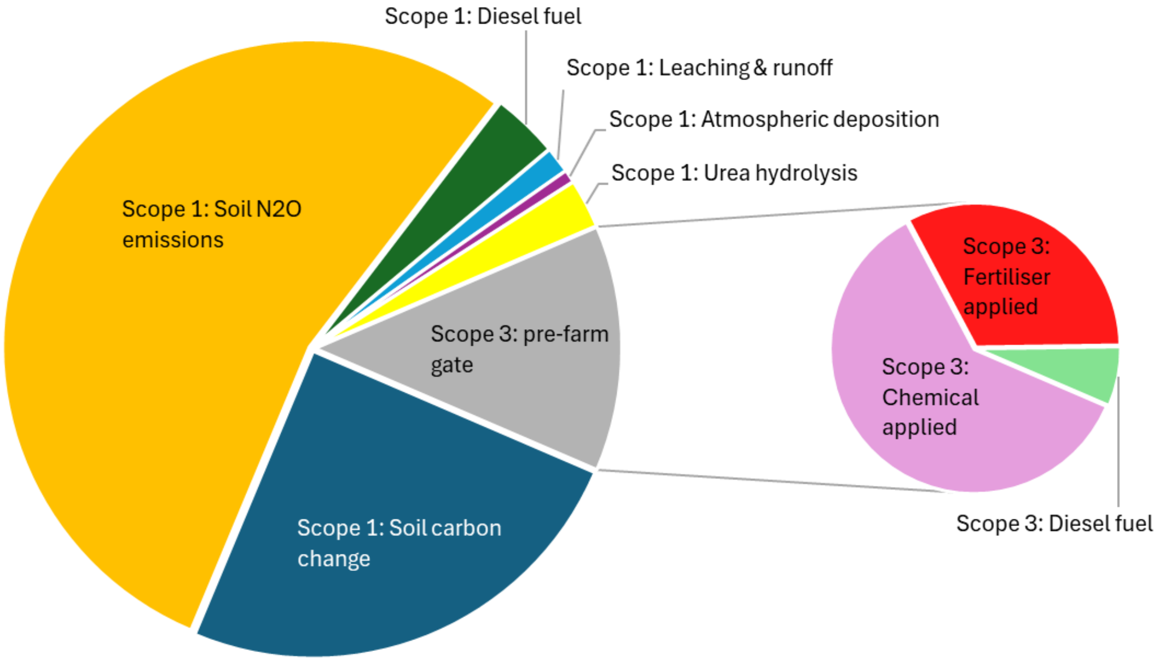

Figure 2. Contribution of different sources of GHG emissions to the net emissions from *Baseline* farming systems (kg CO_2-eq. per ha per year) averaged across all sites over the period 2015–2022.

Farming system impacts on GHG footprint

Emissions before including soil carbon change

There were some consistent trends in terms of relative emissions amongst systems across sites. The *Higher nutrient* strategies, where crops were fertilised to target a maximum grain yield potential, generated higher emissions than the *Baseline*, largely due to elevated N_2O emissions, but also due to slightly higher Scope 3 emissions from fertiliser production and from urea hydrolysis. On average these systems increased emissions by 300 kg CO_2-eq/ha/yr.

The *Higher intensity* farming systems, characterised by more frequent cropping had lower N_2O emissions than other systems, due to the system having less time in fallow and having drier soils that reduced the frequency and size of soil N loss events (e.g. denitrification). On average they had emissions 120 kg CO_2-eq/ha/yr lower than the *Baseline*. Conversely, *Lower intensity* systems, where crops are only grown when the soil profile is full, had longer fallow periods and consequently wetter soils, which led to increased net N_2O emissions compared to their higher-intensity counterparts. On average, these systems had emissions 140 kg CO_2-eq/ha/yr higher than the *Baseline*.

There was large between site variability in response to changing the crop mix via increasing crop diversity or legume frequency. Compared to the *Baseline,* the N_2O emissions from the *Higher legume* system were similar or marginally higher at three sites, lower at one site (Emerald) and significantly higher at two sites; on average emissions were 200 kg CO_2-eq/ha/yr higher than the *Baseline*. This variation appeared to be driven by circumstances when legumes left higher mineral soil N over the subsequent fallow which was then prone to losses (e.g. denitrification). The N_2O emissions from the *Higher crop diversity* systems were reduced at two sites, increased at two sites and were similar at one site; with an overall neutral effect on GHG emissions compared to the *Baseline*. This variation appears to be related to the types of crops implemented to diversify the farming system across the experiments; some sites involved cereals like sorghum, while at others this was replaced by crops like canola or cotton.

Soil carbon change influences system GHG footprint

Incorporating simulated changes in soil C (0-30 cm depth) into the GHG emissions calculations significantly influences the estimated net emissions across sites and between systems. At the Billa Billa and Emerald sites, where simulations were initiated with high measured levels of labile organic C, reductions in soil C contributed to 50–70% of the farming systems' GHG footprint (Figure 3). This corresponds to an annual decrease in soil C ranging from 250 to 450 kg/ha over the experimental period. Measured soil C at both sites has also trended down over the experimental phase. Other experimental sites had relatively stable or minor changes in soil C (150 kg of soil C/ha/year), and in several instances, there was a predicted net C sequestration, which could offset other emissions by up to 550 kg CO_2-equivalent/ha/yr. Notably, some of the higher intensity cropping systems at Pampas were predicted to result in a net C gain over the experimental period, making them GHG positive.

Consistent trends were observed across sites regarding the impact of farming systems on soil C change, which in turn effected the net GHG emissions. Across all sites, the *Higher intensity* farming systems demonstrated a more favourable soil C balance compared to the *Baseline*. This improvement is attributed to the higher biomass (and therefore C) inputs in these systems, resulting from more frequent cropping and reduced time in fallow over the same period. This increase in biomass, combined with lower N_2O emissions, meant that these systems consistently recorded the lowest net GHG emissions. In contrast, the *Lower intensity* systems were predicted to have a negative soil C balance at all sites, performing significantly worse than other farming systems. This adverse outcome is linked to the lower crop frequency, reducing biomass (and C) inputs to counterbalance soil organic matter decomposition over time.

The *Higher legume* systems were estimated to have a more favourable soil C balance than the *Baseline* at most sites. The reasons for this are not entirely clear, but are thought to relate to the lower carbon-to-nitrogen (C:N) ratio of legume residues, which contribute positively to the soil C pools. Although the beneficial effect on soil C was somewhat offset by higher N_2O emissions, the *Higher legume* systems were generally predicted to have lower GHG emissions than the *Baseline* system.

The *High diversity* systems exhibited large site variability in their relative impact on soil C, with some sites showing a positive effect and others neutral or negative. Finally, the *Higher nutrient* strategies were simulated to have a neutral effect on soil C at three sites, and a positive effect at the other three; only at Mungindi was this positive effect large enough to offset the higher N_2O emissions associated with these systems.

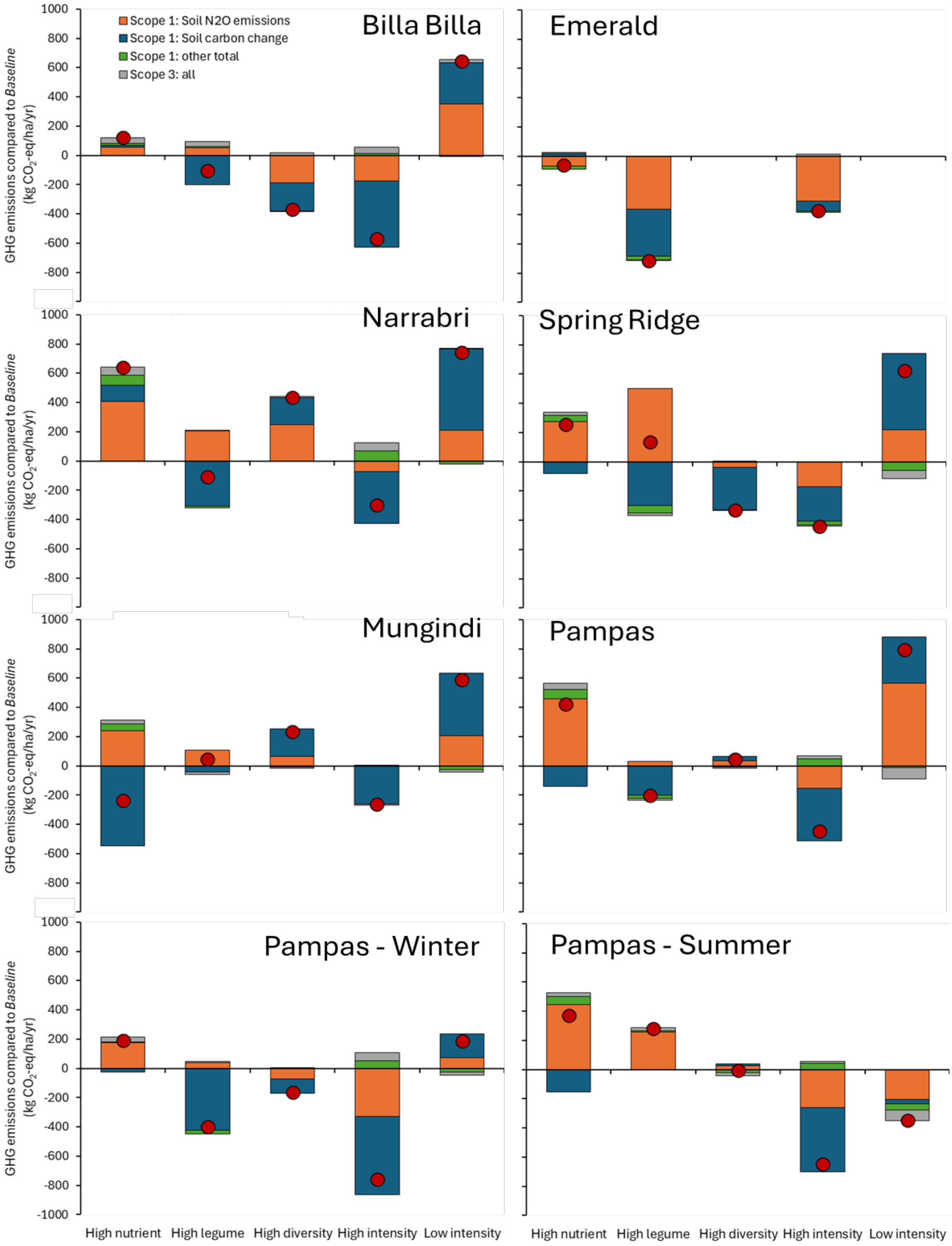

Figure 3. Estimated GHG emissions (kg CO_2.eq/ha/yr) and their sources amongst different farming systems compared to the *Baseline* system at each experimental location over 8-years. Bars indicate the magnitude of change (either positive – increasing emissions, or negative – decreasing emissions) and the red dot is the total change accounting for all computed sources. Sources estimated include on-farm (Scope 1) emissions from N2O coming from the soil and crop residue decomposition, simulated increases or decreases in soil carbon over the life of the experiment, other Scope 1 emissions from fuel use, urea hydrolysis or leaching/runoff losses of N and pre-farm gate (Scope 3) emissions embedded in inputs of fertilisers, crop protection products and fuel.

System interactions

Within the core experiment at Pampas, which evaluated a combination of different farming systems strategies, it was evident that increasing the intensity of the farming system consistently reduced net emissions compared to the lower intensity counterparts (Table 1). Amongst these combinations a system combining *Higher intensity* cropping in combination with *Higher diversity* and *Higher legume* frequency achieved a net C positive outcome over the experimental period of about 800 kg CO_2-eq/ha/yr. However, when *Higher nutrient* input strategies were combined with *Higher diversity* cropping, GHG emissions increased relative to the *Baseline*, and were higher than when these strategies were applied independently.

Table 1. Estimates of net change in annual GHG emissions (including soil C change) across the factorial of farming systems changes compared to the *Baseline* system implemented at the core experiment (Pampas) between 2015 and 2022.

	GHG emissions (kg CO_2-e/ha/yr)	
System	***Moderate intensity***	***High intensity***
Baseline	0	-481
Higher nutrient	+386	+55
Higher legume	-208	-333
Higher diversity	+49	-294
Higher diversity + Higher nutrient	+606	+146
Higher diversity + Higher legume	+87	-797

Emissions intensity

Using the total emissions data, which include simulated N_2O losses and accounted for differences in soil C changes among systems, led to distinct rankings in terms of emissions intensity (i.e. \$/CO_2-eq). The estimated GHG intensities varied significantly across the different farming systems, with values ranging from \$190 to \$1900 per tonne of CO2-eq/ha. No single system consistently emerged as the 'best' in terms of emissions intensity, and rankings varied across sites when comparing gross margin per emissions. However, the systems with the lowest projected total emissions nearly always displayed the highest productivity, both in terms of gross margin returns (Figure 4). This indicates the existence of numerous 'win-win' scenarios, indicating that optimising for system profitability could also lead to optimised GHG emissions intensity.

The *Higher intensity* farming system generated the most favourable emissions intensity at four of the sites but was the least favourable system at Emerald, where the higher intensity system has shown to have much lower returns over the experimental period. On average, these systems produced \$1900 of gross margin return per tonne of CO_2-eq/ha. The *Higher legume* and *Higher diversity* farming systems generated the most favourable GHG intensity at Emerald and Billa Billa sites, respectively. Conversely, the *Lower intensity* systems consistently underperformed across all locations. These systems generated lower annual gross margins and had the highest GHG emissions. In comparison, they generated an average of \$300 in gross margin per tonne of CO_2-eq/ha.

At the core experimental site, where factorial combinations of farming systems were evaluated, the *Higher intensity* systems demonstrated higher returns per kg CO_2 compared to their *Lower intensity* counterparts. The ranking amongst the systems was consistent with their total emissions, indicating that differences in accumulated gross margin did not significantly alter their relative GHG intensity rankings. This consistency suggests that the efficiency gains in terms of GHG emissions are directly correlated with the intensity of farming practices, independent of the economic performance measured by gross margin.

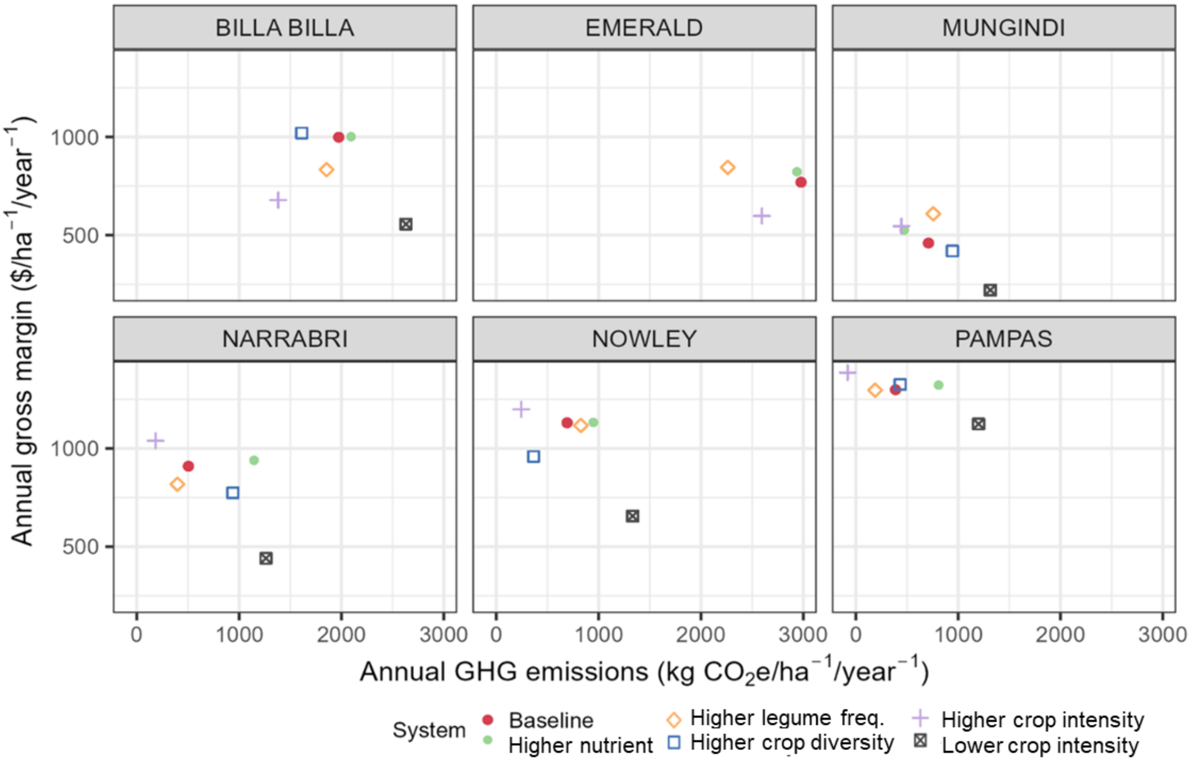

Figure 4. GHG emissions intensity, that is the relationship between estimated annual GHG emissions (Scope 1 & 3) and estimated gross margin of different farming systems over 8-years at the six experimental locations in Australia's northern grain-growing region.

Conclusions

These findings highlight that the GHG footprints of farming systems can vary significantly, with up to a two-fold difference in the main sources of emissions and more than a four-fold difference in emissions per tonne of grain yield or revenue generated. This disparity expands further when changes in soil C are factored into the GHG balance. Typically, farming systems that are more intensive and have fewer idle periods are associated with lower emissions. This is particularly true when accounting for changes in soil C and the reduction of N_2O emissions. In contrast, systems with longer fallows and less time in-crop tend to have the highest emissions. The impact of cropping intensity on emissions proved to be more significant than the choice of crops, which resulted in variable effects on overall GHG emissions across different locations.

This analysis underscores the importance of simulating N and C dynamics to accurately compare different farming systems, rather than relying on static emissions factors that primarily calculate emissions based on activity data, with a particular emphasis on fertiliser inputs. Utilising these more simplistic, yet less comprehensive approaches would have led to vastly different predictions, as they fail to account for impacts on soil moisture states and changes in soil C. The analysis further illustrates that even relatively minor annual changes in soil C can significantly influence the GHG footprint of the production system, acting either as contributors or mitigators. The scale of these predicted changes in soil C are modest enough to pose substantial challenges for measurement, even over decadal time periods. Therefore, alternative approaches are likely to be needed to evaluate the relative impact of different farming systems on soil C, capturing both positive and negative influences.

As farmers face the growing challenge of balancing the environmental footprint of production with the need to produce food, adopting a holistic approach to evaluating different production systems becomes increasingly important. The calculations presented here are one of a few multi-year studies, both nationally and internationally, that directly compare GHG emissions across a variety of farming systems. This research serves as a benchmark for grain production in eastern Australia and offers a detailed insight into how altering agronomic practices, such as crop rotation, nutrient inputs, and cultural methods, can impact GHG emissions and intensities. This analysis not only contributes to our understanding of the environmental aspects of agricultural production but also informs strategies aimed at reducing emissions while maintaining or increasing food production.

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 authors would like to thank them for their continued support.

We acknowledge the various collaborators involved with collecting the experimental data and farmer collaborators for hosting the farming systems experiments across the region.

References

National Inventory Report 2021 (2023) Department of Climate Change, Energy, the Environment and Water. Commonwealth of Australia. https://www.dcceew.gov.au/sites/default/files/documents/national-inventory-report-2021-volume-1.pdf

Sevenster M, Bell L, Anderson B, Jamali H, Horan H, Simmons A, Cowie A, Hochman Z (2022) Australian Grains Baseline and Mitigation Assessment. GRDC Updates, February 2022. https://grdc.com.au/__data/assets/pdf_file/0031/572449/Paper-Sevenster-Maartje-GHG-footprint-Grains-February-2022.pdf

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