Impact of crops and crop sequences on soil water accumulation and use in farming systems—Northern Region

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Research Questions: *Can systems performance be improved by modifying farming systems in the northern grains region? | What are the impacts of crops and crop sequences on soil water accumulation and use?*

Key findings

1. Grain legumes (chickpea, faba bean, field pea, mungbean) often leave more residual soil water at harvest than cereals, this difference is diminished due to lower subsequent fallow efficiencies and hence soil water is often similar at the sowing of the next crop.
2. Higher intensity systems have higher fallow efficiencies while lower intensity systems and those with more legumes have lower fallow efficiencies.

Background

The efficiency of soil water accumulation during fallows and the availability of that soil water for use by crops are key drivers of northern farming system productivity and profitability. Fallow water is stored and used as a buffer for more reliable grain production in highly variable rainfall patterns. So, fallow efficiency (i.e. the proportion of rain that accumulates in the soil profile) is critical, and is influenced by ground cover levels, seasonality or timing of rainfall events, the length of the fallow and the amount of water currently in the soil profile.

While advances in agronomy and the performance of individual crops have helped grain growers maintain their profitability, current farming systems are underperforming. In light of this CSIRO, Queensland Department of Agriculture and Fisheries (DAF), and New South Wales Department of Primary Industries (NSW DPI) collaborated to establish farming systems trial sites at seven northern grains region locations from Central Queensland to Central New South Wales (Emerald, Pampas, Billa Billa, Mungindi, Narrabri, Spring Ridge and Trangie) to evaluate the question; *Can systems performance be improved by modifying farming systems in the northern grains region?*

What was done

Here we compare the differences between different farming system strategies over the four experimental years in terms of fallow efficiency and water use efficiency (WUE) and the resultant impact on gross margin return per mm of rainfall ($/mm). We compare a range of modifications to the *Baseline* farming system strategy:

- **Baseline** approximates common farming system practice in each district: dominant crops only used; sowing on moderate soil water threshold to approximate common crop intensities (often 0.8 crops per year); and fertilising to median crop yield potential.
- **Higher crop intensity** increases the proportion of time that crops are growing by reducing the soil water threshold required to trigger a planting opportunity (e.g. 30% full profile).
- **Lower crop intensity** ensures soil water is >80% full before a crop is sown and higher value crops are used when possible.
- **Higher legume frequency** aims to have every second crop as a legume across the crop sequence and uses high biomass legumes (e.g. faba bean) when possible.
- **Higher crop diversity** uses a greater set of crops with the aim of managing soil-borne pathogens and weeds. Includes 50% of crops resistant to root lesion nematodes (preferably two in a row) and two alternative crops are required before the same crop is grown.
- **Higher nutrient supply** increases the fertiliser budget for each crop based on a 90% of yield potential rather than the baseline of 50% of yield potential.

Results

Crop type effect on subsequent fallow efficiency

Over four years at the seven farming systems sites, we have monitored water accumulation in the fallow following 306 crops. The collated data has been used to compare how different crop types impact on subsequent fallow efficiencies (Figure 1). This data shows the high variability in fallow efficiency that occurs from year to year but it also demonstrates some clear crop effects on subsequent fallow efficiencies.

Higher fallow efficiencies were achieved after winter cereal crops than winter grain legumes and canola. The median fallow efficiency following winter cereals was 0.27, while following chickpea and other grain legumes it was 0.14, with canola intermediate at 0.19. Median fallow efficiencies following sorghum were similar to wheat (0.26), but short fallows after sorghum were more efficient than long fallows. This difference between fallow length was less obvious following winter cereals, most likely due to lower evaporation losses in winter fallows, making them more efficient than summer fallows. Hence, short fallows after sorghum occurring in winter were the most efficient, while long-fallows spanning into summer were less efficient. This also explains the similar fallow efficiency of short (summer) and long fallows (summer + winter) after winter cereals.

Consequently, crop type and its impact on the accumulation of soil water in the following fallow is a key factor to consider in the cropping sequence. For example, a fallow receiving 400 mm of rain after a winter cereal would accumulate 108 mm on average, while the same fallow after a grain legume may only accumulate 56 mm. This difference could have a significant impact on the opportunity to sow a crop and/or the gross margin of the following crop in the cropping sequence.

Fallow efficiency in different farming systems

We have analysed how the different system strategies and their modifications have affected the efficiency of water accumulation over the fallow. Most *Baseline* systems achieve fallow efficiencies of at least 0.20 over the whole cropping sequence.

Higher legume and *Higher crop diversity* systems at some sites have increased the number of non-cereal crops grown. This appears to have reduced fallow efficiency in these systems (Table 1), perhaps from reduced stubble loads and ground cover. Conversely, *Higher nutrient supply* produced crops with greater biomass, which in some cases has allowed small increases in fallow efficiency. Another less obvious trend was that systems with a higher proportion of summer crops had higher fallow efficiency, which may be due to having more fallow periods during the winter when the evaporative potential is lower.

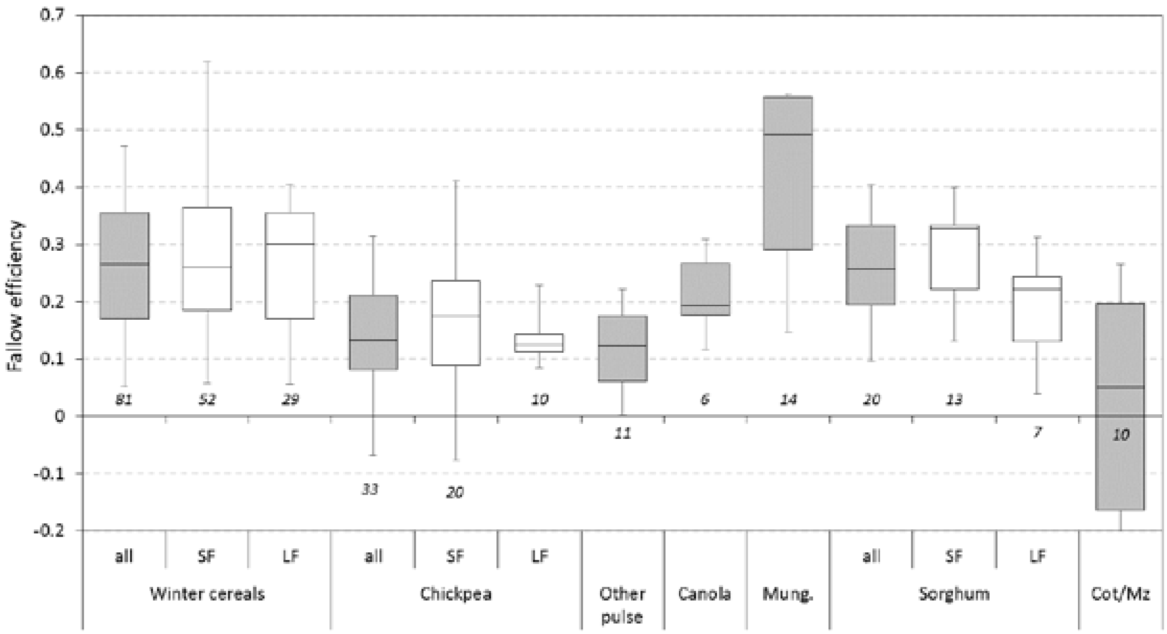

Figure 1. Summary of observed fallow efficiencies following different crops and fallow lengths (SF = short fallows 4-8 months, LF = long fallows 9-18 months) across all farming systems sites and treatments 2015-2018; winter cereals include wheat, durum and barley; other pulses include faba bean and field pea. Boxes indicate 50% of all observations with the line the median, and the bars indicate the 10th and 90th percentile of all observations. Italicised numbers indicate the number of fallows included for each crop.

Table 1. Comparison of efficiencies of fallow water accumulation (i.e. change in soil water/fallow rainfall) amongst different cropping system strategies at 7 locations across the northern grains region.

Crop system	CORE - Pampas			Billa Billa	Narrabri	Spring Ridge	Emerald	Mungindi	Trangie (red soil)	Trangie (grey soil)	All site average
	Mix	Winter	Summer								
Baseline	0.26	0.30	0.25	0.24	0.30	0.20	0.23	0.17	0.08	0.20	0.22
Higher crop diversity	0.21	0.27	0.28	0.28	0.25	0.12		0.34	-0.13	0.23	0.21
Higher legume	0.13	0.21	0.25	0.22	0.25	0.13	0.19	0.14	-0.08	0.28	0.17
Higher nutrient supply	0.23	0.28	0.32	0.29	0.29	0.16	0.23	0.17	0.13	0.29	0.24
Higher crop intensity	0.48			0.35	*	0.28	0.22				0.37
Lower crop intensity	*	0.07	0.21	0.29	0.12	0.16		0.19	-0.03	0.19	0.16

Colouring of numbers indicate the difference from the baseline system: black = similar to baseline; red = large reduction; orange = moderate reduction; light green = moderate increase; dark green = large increase.
*Crop system does not yet vary from the baseline in this regard

The greatest differences in fallow efficiencies resulted from changing the cropping intensity in systems. Shorter fallows and double crops increased fallow efficiency, while having more long fallows reduced fallow efficiencies.

Fallow length effects on crop water use efficiency and gross margin

The previous section demonstrated the system differences in their ability to capture and store fallow rainfall. Consequently, the challenge becomes how to convert that stored water to higher grain yield and returns in the following crops.

Across the seven farming systems sites, 42 fallows of varying length were planted to one of eight common crops allowing a direct comparison of their impact on that crop (i.e. wheat after long or short fallow) (Table 2). These comparisons showed that longer fallow periods (under the same seasonal conditions) have resulted in more plant available water (PAW) at planting of the common crop in 41 of these 42 sequences.

In every comparison, the longer fallow resulted in increased grain yield, which in seven of the eight comparisons improved crop water use efficiency (WUE) i.e. grain yield/(in-crop rain + Δ soil water). The exception was the highest yielding crop, which had the highest WUE in these comparisons (sorghum at Pampas in 2016/17).

It is important to also factor in the fallow rain required to achieve the higher plant available water at sowing. Here we have calculated this as the rainfall use efficiency (RUE) of these crops, i.e. grain yield/ (prior fallow rain + in-crop rain). This shows that once the efficiency of fallow water accumulation is taken into account then, in most cases, there was little difference in productivity of the systems in terms of kg of grain produced per mm of rain, (exclusions were a chickpea crop following a 18-month fallow at Pampas in 2017 and a heat-stressed sorghum double-crop at Pampas in 17/18). Comparing these crops in terms of gross margin per mm of rain ($/mm—including fallow rain) showed that in most cases the best returns were from short fallows, which is the cropping intensity targeted by our *Baseline* systems (Table 2). Table 3 supports this, showing that the *Baseline* systems, with an average of 1 crop per year, had higher crop WUE, RUE and $/mm than both the *Higher crop intensity* and *Lower crop intensity* systems. The *Higher intensity* and *Lower intensity* systems had similar crop WUE to each other, but the *Higher crop intensity* systems achieved a higher RUE than the *Lower crop intensity* systems due to their higher fallow efficiency. Despite the differences in RUE, the gross margin return per mm of rainfall is similar for *Higher crop intensity* and *Lower crop intensity* systems, which is likely a result of incurring more planting and harvesting costs in the *Higher crop intensity* systems, balanced by the potential to grow more higher-value and higher-risk crops in the *Lower crop intensity* systems.

Table 2. Comparison of yield and water use of crops with varying lengths of preceding fallow, for a range of crops and locations. Double crop is 0-4 month fallow; Short fallow is 4-8 month; long fallow is 9-18 months.

Site	Fallow prior	Pre-plant PAW (mm)	Grain yield (t/ha DW)	Crop WUE (kg/mm)	Rainfall UE (kg/mm)	Crop gross margin ($/ha)	$/mm rain
Wheat							
Emerald, 2016	Double crop	100	2.35	8.3	5.3	512	1.15
	Short fallow	177	3.36	9.9	4.2	678	0.85
Billa Billa, 2017	Double crop	65	1.13	5.6	4.2	211	0.78
	Short fallow	125	1.49	6.7	4.5	278	0.84
Pampas, 2017	Double crop	53	1.56	3.4	3.4	258	0.56
	Short fallow	169	1.83	5.2	3.5	424	0.81
Sorghum							
Billa Billa, 16/17	Short fallow	131	0.62	2.3	1.7	-138	-0.37
	Long fallow	212	1.31	3.8	2.3	34	0.06
Pampas, 16/17	Short fallow	147	4.51	10.8	8.2	1033	1.88
	Long fallow	238	5.66	10.6	6.8	1082	1.30
Pampas, 17/18	Double crop	96	0.65	2.2	2.2	30	0.10
	Short fallow	146	4.02	8.4	7.2	775	1.39
Chickpea							
Pampas, 2017	Double crop	45	1.30	3.6	3.6	455	1.26
	Short fallow	169	1.68	6.4	3.8	651	1.47
	Long fallow	162	1.80	6.6	1.6	547	0.49
Billa Billa, 2018	Double crop	163	0.82	4.5	2.7	209	0.69
	Short fallow	203	1.48	6.8	3.1	628	1.31

Implications for growers

These trials show that the systems that most efficiently converted water (stored and rainfall) to grain and gross margin were those with a higher proportion of cereal crops and a cropping intensity of one crop per year. This strategy will ultimately lead to weed and disease problems across the northern grains region, so growers using these systems will need to change the seasonality of their cropping program to provide a disease or weed break. Our results suggest that, despite seasonal outcomes, the average crop WUE and the $/mm returns were similar for a long-fallowed transitions and double-cropped transitions between summer and winter cropping.

Acknowledgements

The research undertaken as part of this project (CSA00050, DAQ00192) is made possible by the significant contributions of growers through both trial cooperation and the support of the Grains Research and Development Corporation and Queensland Department of Agriculture and Fisheries. We would also specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

Table 3. Comparison of water converted to grain yield (crop WUE) efficiencies at the system level for the four sites with both *Higher crop intensity* and *Lower crop intensity* systems. Included are values averaged across the four sites for rainfall use efficiency (RUE), and gross margin returns per mm of rainfall for the life of the trials.

Crop system	CORE - Pampas			Billa Billa	Narrabri	Spring Ridge	System average		
	Mix	Winter	Summer				Crop WUE	RUE	$/mm
Baseline	8.7	7.8	7.8	12.3	5.2	10.9	8.4	6.4	1.67
Higher crop intensity	7.0			6.5	4.8	10.6	6.9	5.4	1.28
Lower crop intensity	5.1	8.0	10.2	8.9	3.8	6.8	6.9	3.8	1.33