Impact of crop type and sequence on soil water accumulation and use in farming systems

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Abstract

The efficiency of soil water accumulation during fallow periods, and the availability of that soil water for use by crops are key drivers of northern farming system productivity and profitabilityIn 2015 seven farming systems experiments were established from Central Queensland to Central NSW. Soil water, nitrogen and pathogens were regularly monitored along with crop biomass, grain yield and variable costs, as measures of system performance. A *baseline* cropping system, representing current commercial practice was established and tested against other systems with higher and lower crop intensity, higher crop diversity, greater inclusion of legumes in the rotation and higher fertiliser inputs. A key driver of northern farming system productivity and profitability is soil water accumulation during fallows periods for use by subsequent crops. We found that winter cereals and sorghum had the highest fallow efficiency (median 0.26), ahead of chickpeas (0.14) and canola (0.19). Short (4-8 months) and long (9-18 months) fallows following wheat had similar fallow efficiency, however lower fallow efficiency was recorded for sorghum stubble with longer fallows (0.33 vs 0.22) Changing cropping intensity had the greatest impact on fallow efficiencies, with increases in *Higher intensity* systems (0.37) and decreases in *Lower intensity* systems (0.16) relative to the *Baseline* (0.22). Varying fallow length has shown increased grain yield and water-use-efficiency for longer fallows, however rainfall use efficiency and gross margin/mm has favoured a 4-6 month fallow. Profitability favours a moderate intensity, with 0.8-1 crops/year providing the greatest return per mm of rainfall.

Key Words

Fallow, fallow-efficiency, water-use-efficiency, gross margin, soil water

Introduction

The efficiency of soil water accumulation during fallow periods, 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. Fallow efficiency (FE) (i.e. the proportion of rainfall 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 in the soil profile. While accumulating more soil water prior to sowing a crop is always preferable, this often requires longer fallow periods, meaning there are additional costs for maintaining that fallow and the number of crops grown declines. In this study we analyse the data from a series of farming systems experiments across seven locations (Emerald, Pampas, Billa Billa, Mungundi, Narrabri, Spring Ridge and Trangie) over four years to explore the question; 'how much does the farming system (i.e. mix of crops and their frequency) and different crops influence the accumulation and utilisation of water?'

Methods

Cropping system strategies

Farming systems trials were implemented at seven locations across the northern grains region (Emerald, Pampas, Billa Billa, Mungundi, Narrabri, Spring Ridge and Trangie) between March 2015 and November 2018. All sites were established as replicated small plot trials (12 m x 25 m plots) with systems replicated four times. A *Baseline* system was established for each site, representing an approximation of current local best management practice. The *Baseline* includes dominant crops used in the district (wheat/barley, chickpea and sorghum); planting crops on a moderate soil water threshold (i.e. >50-60% full profile) for a crop intensities of 0.75-1 crop per year; and fertilising nitrogen for median yield potential. The experiments compared the regional *Baseline* system to modified systems: *Higher crop intensity*, (planting crops on >30% full profile); *Lower crop intensity,* (planting crops on >80% full profiles); *Higher crop diversity*, (growing a wider range of crops to manage disease and herbicide resistance); *Higher legume frequency,* (growing 50% legume crops); or *Higher nutrient supply,* (same crop planted as *Baseline* each season, but increasing fertiliser nitrogen budgets to satisfy 90% yield potential).

Of particular interest is how these system changes impact the capture and utilisation of rainfall over the farming system. We have been sampling soils (0-1.5 m) to determine the plant available water both prior to planting and after harvest of each crop over a sequence of years. This enables the calculation of the fallow efficiency (FE) following particular crops and over the crop sequence as a whole. Over four years at the seven research sites, water accumulation was monitored in the fallow following 306 different crops. We can then calculate crop water use efficiency (WUE) and rainfall use efficiency (RUE) and compare crop types in terms of the conversion of both in-crop and fallow rain in terms of grain yield and gross margin per mm of rainfall.

FE is calculated for each crop as: Δ soil water during fallow/ rainfall over that time, or at a system level as: (∑ Δ soil water during fallow)/(∑ rainfall over those times). WUE is: grain yield/(in-crop rain + Δ soil water) and RUE is similar to WUE but also includes the preceding fallow: grain yield/(prior fallow rain + in-crop rain + Δ soil water). RUE can also be calculated at a system level as: ∑grain yield/(total rainfall + Δ soil water). Gross margins are calculated using actual inputs, with standardised machinery operation costs and 10 year average farm gate commodity prices. Gross margin per mm of rainfall ($/mm) can then be calculated as: gross margin/(rainfall + Δ soil water). Fallows are grouped by length for comparison in this report: double-cropped (0-3 months); short-fallow (4-8 months); and long-fallow (>9 months).

Results

Crop type effect on subsequent fallow efficiency

This data shows that there is high variability in fallow efficiency from year to year and also demonstrates some clear crop effects on subsequent fallow efficiencies (Figure 1). Higher fallow efficiencies (median 0.26) were recorded after winter cereal crops than winter grain legumes (median 0.14), and to a lesser degree, canola (median 0.19). Median fallow efficiencies following sorghum were similar to wheat (0.26), but short fallows after sorghum were more efficient than long fallows (0.33 vs 0.22 respectively). Lower and highly variable fallow efficiencies were observed after maize or cotton compared to sorghum, owing to the lower ground cover and often long fallows following these crops. Somewhat surprising was the high fallow efficiencies after mungbean, these were typically very short fallows, often with significant cover still present from a previous winter cereal crop.

Differences observed between short and long fallows were 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 accumulated 56 mm, due to its lower fallow efficiency. 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.

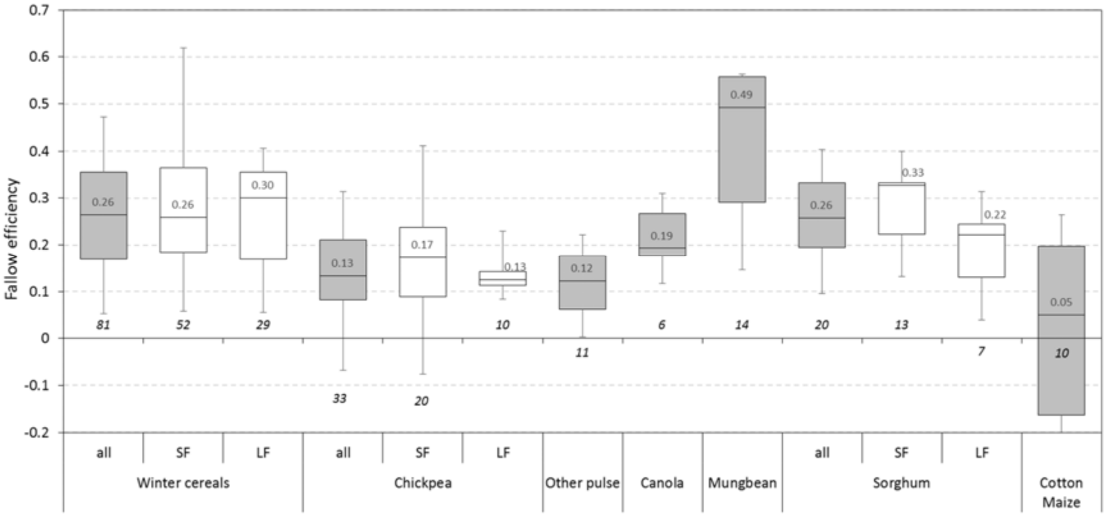

Figure 1 Summary of observed fallow efficiencies following different crops and different fallow lengths (SF – short fallows 4-8 months, LF – long fallows 9-18 months) across all farming systems sites and treatments between 2015 and 2018; winter cereals include wheat, durum and barley; other pulses include fababean and fieldpea. 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.

Fallow efficiency under different farming systems

We have also found that across the crop sequence different system strategies have affected the efficiency of water accumulation over the fallows. Most *baseline* systems achieve fallow efficiencies of approximately 22% ± 4% over the whole cropping sequence.

The greatest differences in fallow efficiencies resulted from changing the cropping intensity in systems. *Higher intensity* systems with shorter fallows and more frequent double crops increased fallow efficiency, while having more long fallows reduced fallow efficiencies in *lower intensity* systems.

Higher legume systems, and at some sites, *higher diversity* have increased the number of non-cereal crops grown. This appears to have reduced fallow efficiency in these systems (Table 1), particularly where crops grown have reduced stubble loads and ground cover. Conversely, increased nitrogen fertiliser input (*higher nutrient*, with the same crop sequence as the *baseline*) produced crops with greater biomass, which in many cases has allowed small increases in FE.

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

*Crop system does not yet vary from the baseline in this regard

Fallow length effects on crop water use efficiency & gross margin

While we found that less intense systems accumulate water in fallows less efficiently, this doesn't necessarily translate into lower system WUE, since crops sown on more soil water can convert that stored water to higher grain yield and returns more efficiently than crops grown on marginal soil water.

Across the seven farming systems sites we compared several crops grown in the same season that were proceeded by different fallow lengths i.e. Wheat after long or short fallow (**Error! Reference source not found.**). These comparisons showed that in most cases the longer fallow periods (under the same seasonal conditions) have resulted in more plant available water (PAW) at planting of the common crop, which in-turn had higher grain yield. Crop water use efficiency (WUE) was higher for higher grain yield under the same growing conditions, which in seven of the eight comparisons followed the longer fallow.

However, while crop WUE may be increased after longer fallows, it is important to also factor-in the fallow rain required to achieve the higher plant available water at sowing. Hence, the rainfall use efficiency (RUE) of these crops, 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 grain produced per mm of rain.

Once the profitability of these crops ($/mm) showed that in most cases the best returns were from crops with 4-6 months of fallow. This aligns with the cropping intensity targeted by our *baseline* system. Consequently, the *Baseline* systems have achieved higher RUE and $/mm than both *Higher intensity* and *Lower intensity* systems. The *higher intensity* systems achieved a higher RUE than the *Lower intensity* systems due to the higher fallow efficiency of short fallows, but the gross margin return per mm of rainfall is similar for *Higher intensity* and *Lower intensity* systems, which is likely a result of incurring more planting and harvesting costs in the *Higher intensity* systems, balanced by the potential to grow more higher-value and higher-risk crops on stored PAW in the *Lower intensity* systems with lower variable costs.

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

Conclusion

Systems that most efficiently captured and stored rainfall for use by crops were those that had a higher proportion of cereal crops and a higher cropping intensity. However, there is a trade-off between maximising crop WUE and fallow efficiency that must be balanced in the farming system. Based on our data so far it seems that systems targeting 0.8-1.0 crop per year are those that optimise this relationship.

The use of PAW thresholds to trigger planting decisions has been effective in forcing differences in fallow length across a range of wetter than average and drier than average seasons. *Baseline* planting triggers provided 0.75-1 crop per year; *Higher crop intensity* systems, with lower PAW planting triggers have produced more double crops planted (1-1.3 crops/year); and *Lower crop intensity* systems, with higher PAW planting triggers has required longer fallows to accumulate sufficient PAW for planting (0.5-0.75 crops per year).

In the northern grain region growers will change between summer and winter crops as a means of managing weeds and diseases. Our results suggest that while RUE favours a *Higher intensity* system, on average the $/mm returns were similar for long-fallowed transitions and double-cropped transitions between summer and winter cropping, with double-crops more profitable in the wetter 50% of years and long-fallows more profitable in the drier 50% of years.

We also found, systems with crop intensities of 0.8-1.0 crops per year (i.e. 66-75% time in fallow) achieved fallow efficiencies of 21-24%. These results are lower than historical research (Robinson & Freebairn 2017), which showed fallow efficiencies of 32% (16-43%) under no-tillage systems. This lower efficiency appears to be a result of current systems using more legumes and summer crops that achieve lower fallow efficiencies.

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References

Robinson JB, Freebairn DM (2017) Estimating changes in Plant Available Soil Water in broadacre cropping in Australia. In: Proceedings of the 18th Australian Society of Agronomy Conference, Ballarat, Vic. (http://www.agronomyaustraliaproceedings.org/).