Drivers of system water use efficiency in cropping systems of Australia's northern grains zone

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Abstract

Farming systems experiments were undertaken across multiple sites spanning Australia's northern grains region. A regional baseline of local current best practice was compared with several cropping system strategies that varied in cropping intensity (i.e. number of crops sown/yr), crop choices and nutrient application strategy. Crop yields, inputs and soil water dynamics were monitored in each system over 3.5 years to calculate the system water use efficiency (WUEsystem), i.e. the $ gross margin per mm of system water use (rainfall + change in soil water). Large gaps in profitability were found between the best and worst systems at each site ($200-700 per year between systems). Increasing crop intensity increased costs and either reduced or equalled the system water use efficiency (WUE) compared to the baseline systems at most sites. A promising lever to enhance farming system profitability is therefore, adjusting crop intensity to environmental potential. Increasing grain legume frequency achieved similar profitability and system WUE as the baseline. Increasing crop diversity and growing alternative crops increased costs but also profitability at some sites by managing diseases or weeds. Increasing nutrient supply incurred higher costs and as yet has rarely increased system profitability. Additional nutrients only increased system WUE when one crop in the sequence experienced > median rainfall (i.e. Trangie & Emerald).

Key Words: gross margin, costs, income, nutrients, crop rotation

Introduction

Leading farmers in Australia's northern grains region perform well in terms of achieving the yield potential of individual crops. However, the performance of the overall system is harder to measure and often overlooked in research efforts. Analysis suggests that fewer than one third of crop sequences achieve more than 80% of their potential water use efficiency despite having adequate nitrogen fertiliser inputs (Hochman et al. 2014). Rather than in-crop agronomy, the key limiting factors have related to crop rotations and issues that span crop sequences such as poor weed management, disease and pest losses, sub-optimal fallow management and cropping frequency. Similarly, farming systems are threatened by the emerging challenges of increasing herbicide resistance, declining soil fertility and increasing soil-borne pathogens, all of which require responses to maintain total system productivity. Farming systems are required that better integrate practices to maximise capture and utilisation of rainfall; reduce costs of production and climate-induced risk; ease the decline in chemical, physical and biological fertility; improve crop nutrition and synchrony of nutrient supply; suppress or manage crop pathogen populations; reduce weed populations and slow the onset, prevalence of herbicide resistance.

A farming systems research approach can address the multi-faceted nature of these challenges by relating various practices or interventions in terms of synergies or trade-offs and assess impacts on productivity, risk, economic performance and sustainability at the whole-farm level. In this research we used the key metric of "system water use efficiency" to compare system productivity or profitability per mm of rain across environments and cropping systems. Importantly, this differs from commonly used 'crop water-use efficiency' as it captures multiple years, with different crops, and accounts for both rainfall capture and loss over fallow periods of crop sequences, differences in required inputs, as well as the productivity of different crops which may be influenced both positively, or negatively, by previous crops in the sequence or rotation. Hence, we have evaluated the system WUE as the $ gross margin return per mm of system water use (i.e. rain minus the change in soil water content) over the period of interest.

$$System\ WUE\ (\$\ GM/mm) = \frac{\sum\{(\text{yield}\ \times\ \text{price}) - \text{variable costs}\}}{(\sum rain + \ \Delta\, Soil\ water)}$$

Methods

Experiments were established at seven locations; a large factorial experiment at Pampas near Toowoomba (38 systems) and 6-9 locally relevant systems at six regional centres across central and southern Qld (Emerald, Billa Billa, Mungindi) and northern NSW (Spring Ridge, Narrabri and Trangie). Across these experiments the farming systems differed in crop intensity, crop choice and fertiliser inputs (see Bell et al. 2017). Farming system strategies varied across locations, depending on the climate and soil conditions.

Baseline – an approximation of current best management practice in each district against which each of the system modifications are compared: Only includes dominant crops for the district; crops are sown on a moderate soil water threshold (i.e. 50-60% full profile, 100-150 mm PAW) to approximate moderately conservative crop intensities (often 0.75-1 crop per year); and fertilising to median crop yield potential.

High crop intensity – aims to increase the proportion of rainfall transpired by crops and reduce unproductive loses by increasing the proportion of time that crops are growing; this is implemented by reducing the soil water threshold required to trigger a planting opportunity (e.g. 30% full profile, 60-100 mm PAW)

Low crop intensity – this aims to minimise the risk of un economical crops by only growing crops when plant available soil water approaches full (i.e. > 80% full) before a crop is sown and higher value crops are used when possible. This requires longer fallows and lower crop intensities relative to the baseline.

High legume frequency –every second crop in the crop sequence is set as a legume and a high biomass legumes (e.g. fababean) is selected when sowing can occur at the appropriate time and allowing for sufficient time between the same species.

High crop diversity – a greater set of crops are used with the aim of managing soil-borne pathogens and weed herbicide resistance risk through crop rotations. This is implemented by designating 50% of crops to those that are resistant to root lesion nematodes (preferably 2 in a row) and a crop sequence with crop followed by 2 alternative crops prior to replanting.

High nutrient supply – increasing the fertiliser budget for each crop based on 90% of yield potential rather than the baseline of 50% of yield potential.

System water-use-efficiency

Data on the grain yields of crops, the total inputs of fertilisers, seed, herbicides and other pesticides, and operations were collected for each system over the 3.5 experimental years of experiments. This was used to calculate the accumulated income and gross margins for each of the cropping systems deployed at each location. Commodity (10-year average adjusted for inflation) and input prices were consistent across all locations to avoid introducing discrepancies in the data (Table 1). All grain yields were corrected to 12% moisture irrespective of harvest moisture levels.

Table 1. Commodity prices (10-year average) for each crop grown across the farming systems experiments

Crop	$/t grain[#]
Barley	218
Wheat (durum & APH)	269
Canola	503
Chickpea	504
Fababean	382
Fieldpea	350
Sorghum	221
Maize	281
Mungbean	667
Sunflower	700
Cotton	1090 ($480/bale lint)

[#] *farm gate price with grading & additional harvesting costs already deducted*

Prices of fertilisers, herbicides, other pesticides and seed were based on market prices at purchase for each input. Costs for operations differed by crop to reflect different contract rates or machinery requirements. There was no correction for overhead or other fixed costs associated with the farming enterprise, although these are likely to vary significantly from farm to farm and region to region.

Results

As would be expected the total income and gross margins varied substantially across all sites, owing to the difference in rainfall, and hence crop productivity, and input costs required. Costs varied across sites, due to differences in starting nutrient levels and weed status, which greatly influenced Gross Margins (GM). For this reason, we focus mainly on comparing the economic outcomes between systems at the same site.

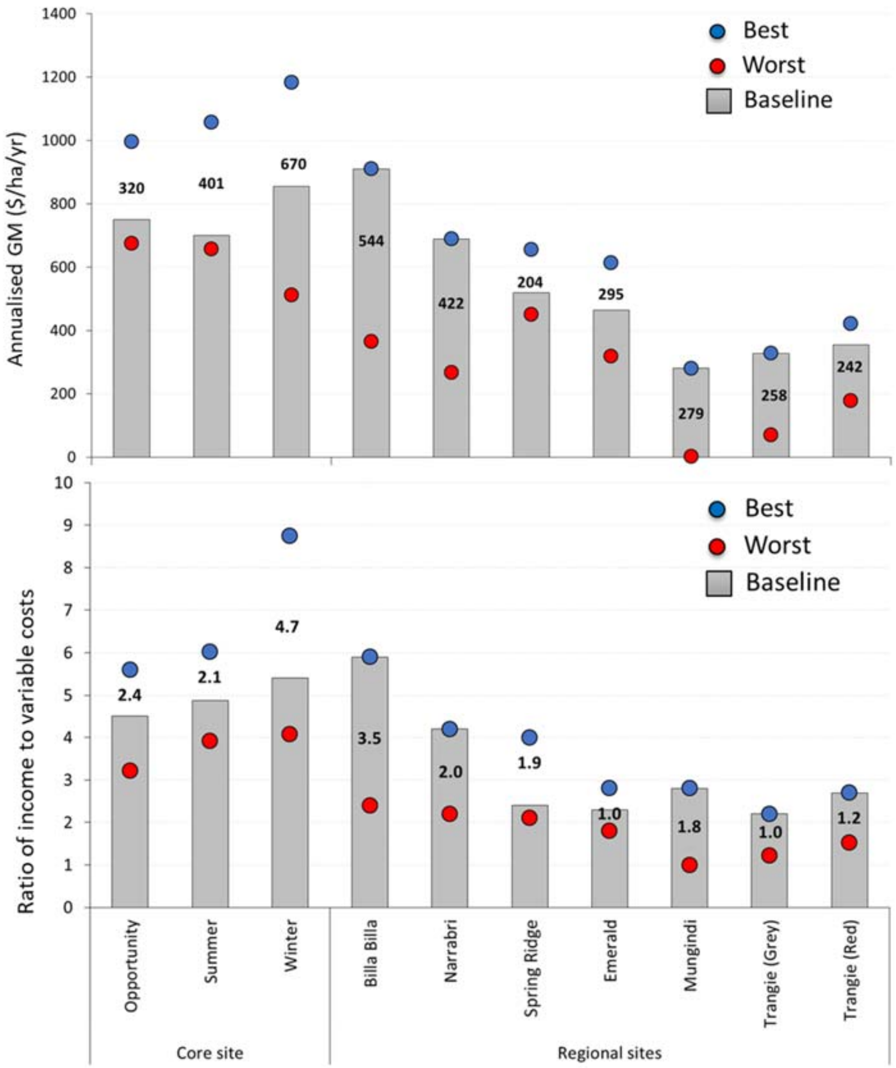

Figure 1. Range in system gross margin ($/ha/yr) and ratio of income to variable costs between the best and the worst performing farming systems, compared to the baseline across 8 farming systems experimental sites.

Cropping system comparisons based on system gross margin and the ratio of income to variable costs, identified significant differences between the best and worst cropping systems within each experiment (Figure 1). The differences between system gross margins was greatest at the core site in the winter rotation systems ($670/ha/yr) and least at Spring Ridge ($210/ha/yr). Similarly large gaps were observed in the return on variable cost ratios across the sites (1.0 – 4.7 difference). The system rankings for this metric were not consistent. Overall, the profitability of farming systems within a particular setting varied significantly. The system rankings for this metric were also inconsistent across experiments. At most regional sites (except Emerald), the baseline cropping system performed the best or as well as any altered system. At Emerald, the High legume and High fertility systems performed the best, $150/ha/yr. higher than the baseline. Amongst the Pampas systems, the gross margin returns of the baseline systems was exceeded by systems with higher crop diversity or high legume frequency by $120-$380 per year over the experimental period.

A common set of modifications to the farming systems were introduced across several sites (i.e. *higher nutrient, higher legumes, crop diversity, higher intensity, lower intensity*). The impact of those changes on economic performance was estimated and presented as a proportion of that achieved in the baseline (Fig. 2). The estimation included the system WUE ($ GM/mm) to account for climatic differences (Fig. 2). The high legume frequency and high nutrient strategies achieved WUE similar to the baselines at most sites. However, the higher crop diversity systems had highly variable impacts on system WUE, with increased WUE at some sites and prohibitively large costs at others. At the most favourable environments (Pampas, Spring Ridge and Narrabri), higher cropping intensity achieved similar or slightly higher system WUE, however, there was a large cost from this strategy at other locations. Similarly, lower intensity systems also reduced system WUE at several sites, while others showed no improvement from the baseline.

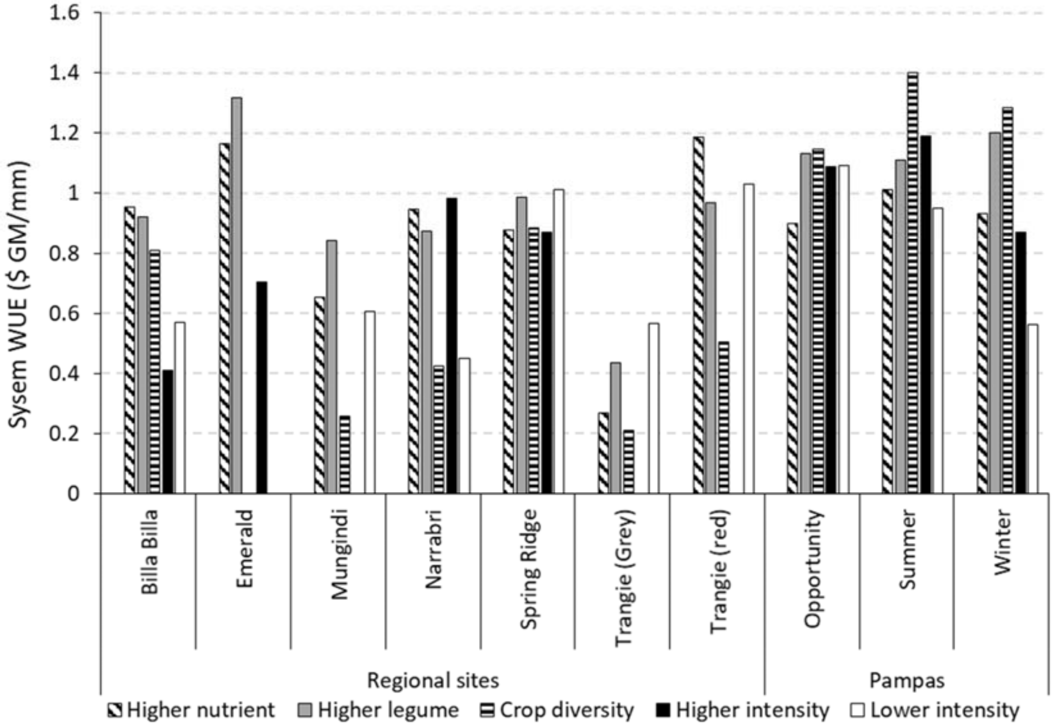

Figure 2. Relative system water use efficiency (i.e. $ GM/mm) of modifying farming systems compared to the baseline at 5 regional sites and under 3 different crop rotations at the Core site (Pampas). Over the 4 experimental years, the baseline systems have sown 4 crops Pampas and Emerald and 3 crops at other sites, low intensity have sown 2 crops at all sites and the high intensity systems have sown 5 crops at Pampas, Billa Billa and Emerald, but the same as baseline at other locations.

Conclusion

This evaluation of farming system performance integrates many of the various factors that may influence their short and long-term productivity (water use efficiency, nutrient inputs and balance, yield responses to crop rotation). Across all farming systems sites, several of the modified farming systems could achieve similar or even greater profits, however this was not consistent across all sites. That is, in many cases there are options to address particular challenges (e.g. soil-borne diseases or weeds, nutrient rundown) that can be profitable. However, in some locations the options seem much more limited, particularly where risky climatic conditions (or challenging soils) limit the reliability of alternative crops in the farming system. The results here provide a snapshot in time over only a 3.5 year period. The longer term impacts of some of these farming systems strategies may yet to be fully realised and hence, some consideration of these results against this longer-term view is also required. Simulation analysis of crop sequences across a wide range of seasonal and soil conditions should allow greater exploration of risk and sustainability of these system strategies.

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