Simulating the efficiency and resilience of diverse crop sequences in Australia’s subtropical cropping zone

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Abstract

Farming systems in Australia’s subtropics have been under-performing. This study used simulation modelling to evaluate common crop sequences used in subtropical Australia in terms of their system water-use-efficiency (WUE) and resilience to climate variability. The analysis here examines this for 4 locations spanning the subtropical farming systems of eastern Australia. We found significant variation in the system WUE ($/ha/mm) amongst crop sequences, with common crop sequences in each location found to be 12-40% less WUE than the best crop sequence. Cropping intensity is a key driver of system profitability and risk, more so than a mix of crops used. Crop systems with higher intensities (i.e. less time in fallow) have higher average profitability but also higher risk; conversely, crop systems with longer fallows have a lower risk but there are trade-offs of lower long-term gross margins. It is critical to match cropping intensity to the environment to optimise the risk-return trade-offs. Lower crop intensities (0.5-0.75 crops/yr) are optimal in harsher environments (e.g. western districts), moderate crop intensities (0.75-1.0 crops/yr) in the moderate environments, but crop systems with higher crop intensities (1.0-1.3 crops/yr) are optimal in higher rainfall environments.

Key Words: Modelling, risk, gross margin, climate variability

Introduction

Farming in Australia’s subtropics is facing many challenges. Analysis has shown that 70% of fields were achieving < 80% of their water limited production potential over a 6 year period (Hochman *et al*. 2014). The region experiences a highly variable climate, hence, designing a cropping system that mitigates these risks is central to the long-term viability of a farming enterprise. Growing crops after a period of fallow to accumulate soil water prior to sowing is a key mechanism for buffering crops against periods of low rainfall (Freebairn *et al.* 2006). However, periods of fallow must be balanced with time in crop to maximise the efficiency of water capture and use. Farming systems in the region are also highly diverse, involving opportunities to grow both summer and winter crops. A wide diversity of crops can be used and a large range in cropping intensities (from 1.5 to 0.5 crops per year) is possible. Hence, a critical question is ‘*What mix of crops & cropping intensities define more effective sequences across environments in the region?’*

This analysis set out to examine this question by systematically simulating a diversity of crop sequences currently used across environments of Australia’s northern cropping zone. It is important to capture the dynamics over the whole crop sequence as there are benefits and costs transferred from one crop to another that influence the efficiency of the system as a whole (e.g. nitrogen supply, residual soil water, ground cover influencing fallow water accumulation). The APSIM model (Holzworth *et al.* 2014) was used in combination with other simulation models to examine the relative performance of these crop sequences against multiple objectives; profitability, riskiness, productivity, WUE, fertiliser input use and efficiency and risks for multiplication of nematodes, herbicide resistance and soil carbon depletion.

Methods

Simulation approach & rules

Using historical climate data for several locations across the northern grains region (Central-west NSW to Central Qld) long-term simulations (110 years) of 18 common cropping sequences were conducted in APSIM. Here we only present data from 4 illustrative sites (Cecil Plains, Eastern Darling Downs; Narrabri, North-west NSW; Mundundi, Western Qld/NSW; Trangie, Central-west NSW). The sequences simulated here vary in their cropping intensity (from 0.5 to 1.3 crops per year), a mix of crops, and summer/winter dominance (Table 1). The simulated sequences were set and were defined by rules which ensured each crop in the sequence was sown if an opportunity occurred in their sowing window or at the end of the recommended sowing window, even when moisture levels were marginal. All cereal crops were fertilised to ensure 200 kg of N was available at sowing and legumes were not fertilised. All sequences simulated are based on a no-till system with full stubble retention using a common good cropping soil in each district (i.e. plant-available water-holding capacity (PAWC) for wheat at Cecil Plains – 290 mm, Narrabri – 176 mm, Mungundi – 186 mm and Trangie – 180 mm). Simulations were phased so that each crop in the sequence was present in each year of the climate record. These long-term simulations generated predictions of crop yields, dynamics of soil water and nitrogen accumulation and use during fallows and under crops.

Sequence economic performance

Sequence annual gross margin ($/ha/yr) was calculated using simulated outputs of grain yield, N requirements and number of weed germination events during fallows, using the equation below. These assumed long-term average grain prices and current variable input prices for each crop (Table 1). Downside risk for each sequence was calculated from the average gross margin in the worst 20% of simulated years.

$$GM_{seq}(\$/\mathrm{ha/yr}) = \frac{\sum\{(\text{Grain yield} \times \text{price}) - (\text{kg N} \times 1.3) - (sprays \times 17) - \text{variable costs}\}}{no.of\ years}$$

Table 1. Assumptions of crop prices and variable costs used in gross margin calculations for crop sequences

Crop	**Average price ($/t)** (after transport)	**Variable costs ($/ha)** (excl. N fertiliser & fallow sprays)
Wheat	240	175
Sorghum	205	218
Chickpea	400	284
Fababeans	380	341
Mungbean	550	276

Results

Crop intensity (% of time in crop) was found to be a major driver of gross margins of the crop sequence, irrespective of the mix of crops used (Figure 1). Figure 1 plots the relationship between the period of time in fallow (i.e. no crop actively growing) and the average gross margin across the 22 crop sequences, varying in their mix of crops and intensity of crops in the sequence. This shows that the environment has a large influence on these relationships. Mungundi has a very flat relationship indicating that crops across a wide range of intensities (from 55-80% time in fallow) generate very similar average gross margins. Meanwhile, at Trangie and Narrabri there is a reduction in average sequence yield as time in fallow increases (i.e. crop intensity declines). This relationship is even steeper at the higher rainfall and more favourable location of Cecil Plains.

While it is important to consider the average annual returns of the crop sequence as a whole, it is also important to quantify the risk associated with the crop sequence. While there are a range of ways 'risk' can be quantified, here we calculate the average gross margin in the worst 20% of years. Hence, systems with a higher return in these poor years are those that are less prone to negative or very poor gross margins and are less 'risky'. Figure 1 shows that at all sites, rotations with more time in fallow were those with lower risks (due to higher soil water available at sowing) while higher crop intensities (i.e. less fallow time) increased the risk of low returns in poor seasons (due to more marginal soil water sowing conditions). Again, this relationship was more associated with crop intensity than it was the mix of crops grown. This relationship between higher risk with increasing crop intensity was most severe in lower rainfall or more marginal environments, such as Mungundi, but Narrabri and Trangie also demonstrated a strong negative relationship. At Cecil Plains cropping intensity (i.e. time in fallow) was less strongly related to risk, meaning that the downside of higher crop intensities was lower.

Average sequence gross margin was highest in sequences with less time in fallow and a greater proportion of rainfall transpired. These analyses clearly show that in most grain production environments there is a significant trade-off between higher potential average gross margins per year and increasing risk, and this is closely associated with cropping intensity. So, for a particular environment, it is important to know which crop systems maximise the returns per unit of risk. In Figure 2 we plot the average long-term returns against the downside risk for the full range of 22 crop sequences to see which crop sequences and their associated cropping intensities are optimal against these two competing factors. Sequences located further to the top right are found to be more optimal in terms of maximising the return-risk trade-off for each location (i.e. higher return with lower downside risk or higher returns in the worst years). If a crop sequence achieves a lower gross margin for a given unit of risk, then it is sub-optimal in terms or risk-return. The crop sequences at the frontier of this trade-off have been highlighted for each location. This figure shows that at Mungundi low intensity crop sequences (0.5-0.75 crops/yr -SxxWxChxWxx, WxxxChxxx; x ≈ 6-month fallow, Ch – chickpea, S = sorghum, W = wheat) were optimal, while at Cecil Plains higher intensity crop sequences (1.0-1.3 crops/yr) were optimal. Narrabri and Trangie were intermediate with varying crop sequences ranging from 0.5-1.0 crops/yr presenting different risk-return propositions that may be tailored to the particular farmers risk appetite or financial position.

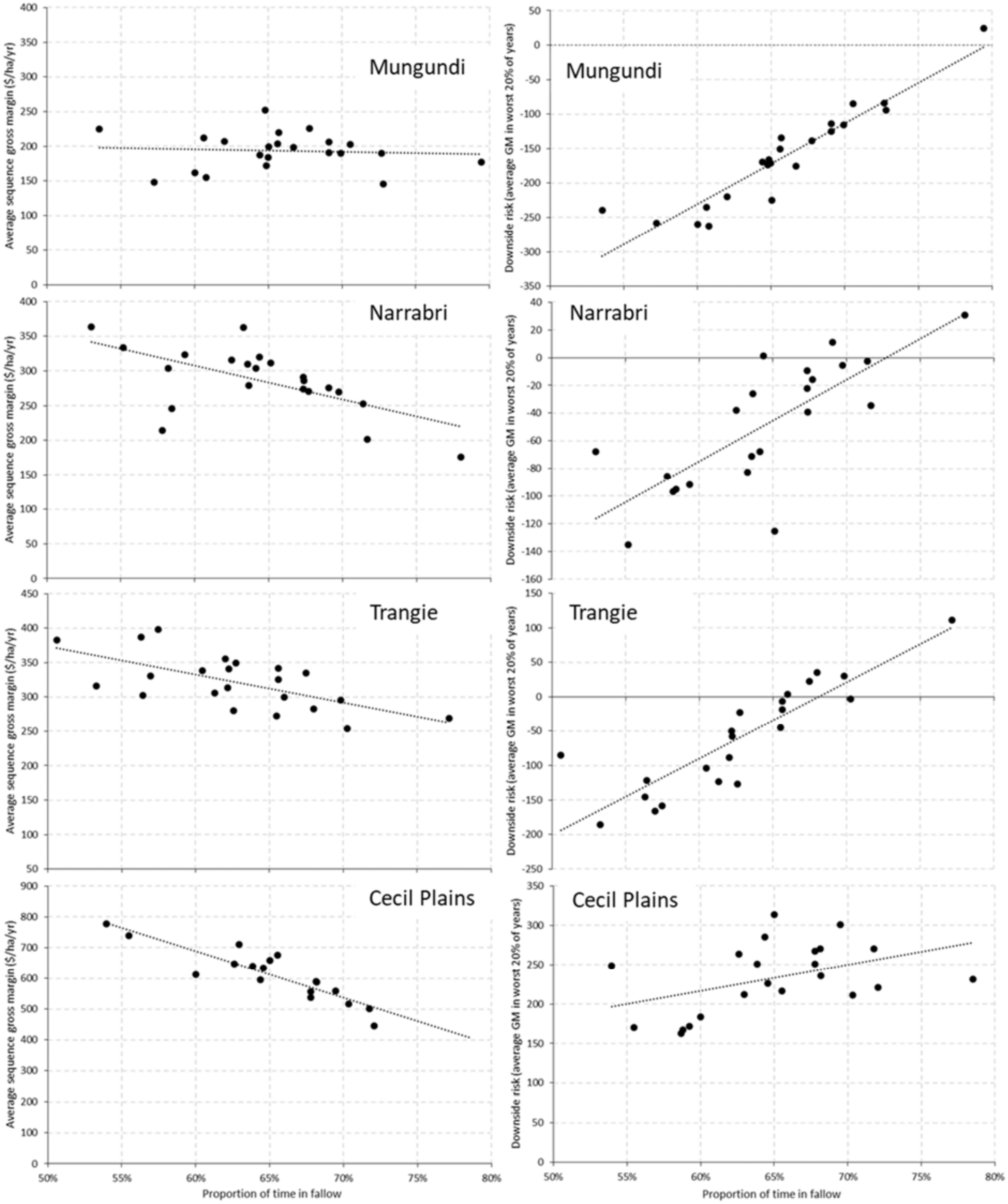

Figure 1. Relationship between proportion of time in fallow and average crop sequence gross margin (left) and downside risk (ie. average gross margin in the worst 20% of years) (right) for 22 crop sequences across 4 different locations in the northern grains zone.

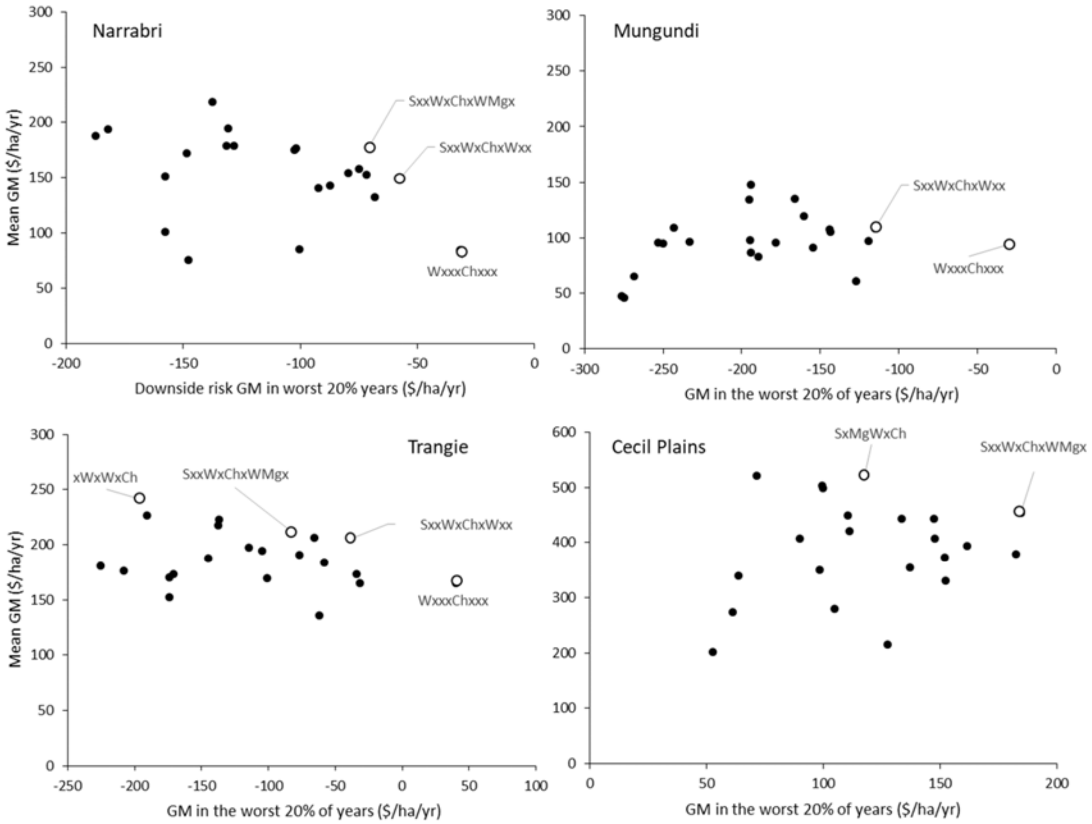

Figure 2. Relationship between long-term average annual gross margin and downside risk (i.e. gross margin in the worst 20% of years) amongst 22 crop sequences at 4 locations across the northern grains zone. Crop sequences with the highest return per unit of risk are highlighted (○) (x ≈ 6-month fallow, S – sorghum, W – wheat, Ch – chickpea, Mg – mungbean).

It is also worth noting that in these locations mixtures of summer and winter crops offer lower risks than systems dominated by summer or winter crops only. This is associated with mixing the range of crops up to utilise seasonal opportunities and buffer the system against climate variability. Such systems where summer and winter crops are used in the crop sequence also allows for mitigating risk through employing some long-fallows leading into key crops (e.g. sorghum or cotton preceded by a long fallow) or stabilising the yield of the first winter crop after a long-fallow). Further risk mitigation would also be provided through buffering against price variability by using a variety of crops where prices are not linked. There are also likely to be a range of agronomic benefits from using summer crops regularly in the crop rotation.

Conclusion

Simulation analysis has allowed a long-term view of the relative profitability and risk-return relationships for cropping systems commonly deployed across the northern grains zone. This has shown that cropping intensity is a key driver of system profitability and risk, but this relationship varies significantly with the cropping environment. Tailoring the cropping intensity suitable for your environment is a critical factor to balance the trade-off between risk and return across the crop system. There are many crop sequences that are suboptimal in a particular environment, and the gaps can be significant; hence, there is significant opportunity to alter the farming system to fit the risk appetite of the farmer and their enterprise.

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