Design of sustainable dryland crop rotations require value judgments

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Abstract

Agricultural sustainability is an aspiration to achieve multiple goals including positive production, environmental and social outcomes. We used cropping systems simulation to compare the sustainability of alternate crop rotations using multiple (eleven) sustainability indicators for 26 crop rotations throughout Australia's subtropical cropping zone. The attributes with environmental impacts such as N applied, N leached, runoff and GHG emissions as well as attributes with economic impacts such as energy and protein produced, revenue, profit, and financial risk of the 26 crop rotations were quantified. Sustainability polygons provided a holistic visualization of the sustainability of four contrasting sites, showing that trade-offs are required between the various sustainability indicators.

Keywords

Sustainable intensification, greenhouse gas emissions, sustainability polygons, subtropical cropping

Introduction

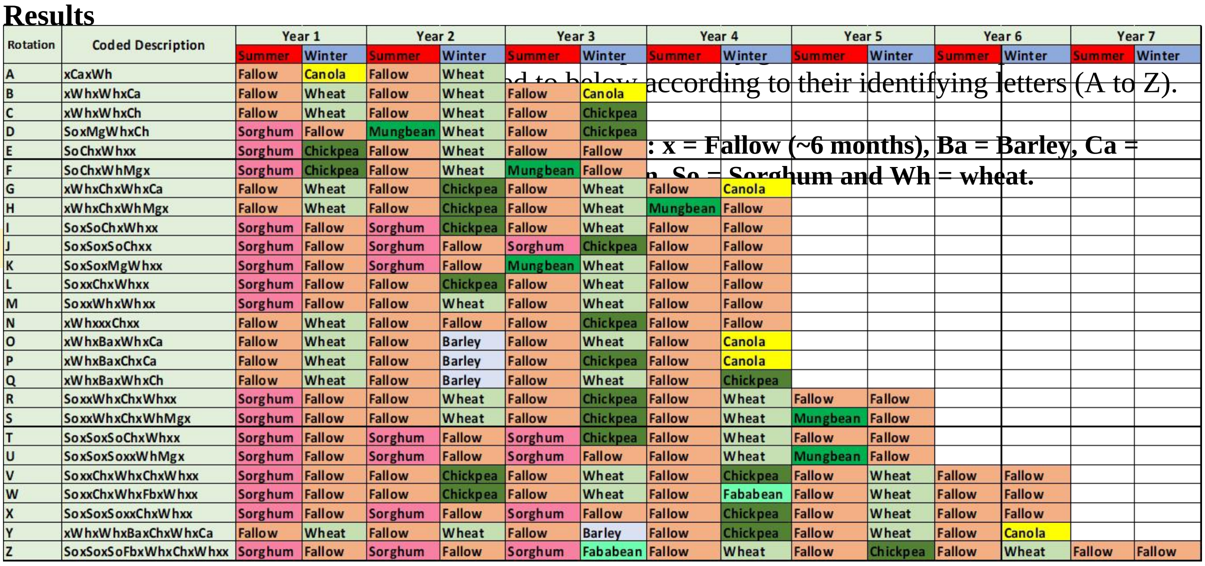
The National Farmers' Federation has set ambitious production targets to grow the value of Australian agriculture from around $60 billion in 2019 to $100 billion by 2030 (https://www.talking2030.com/) while also committing Australian agriculture to play its role in moving towards an economy-wide climate neutral goal by 2050 whilst maintaining productivity and profitability (https://nff.org.au/wp-content/uploads/2020/08/2020.08.06_Policy_NRM_Climate_Change.pdf). For such goals to be achieved agricultural science must provide a fuller accounting of both the costs and benefits of alternative agricultural practices as the basis of policy and action to maximize the net benefits of agriculture. Crop rotations alter the species diversity and cropping intensity, which in turn impact on the abiotic and biotic environment by influencing soil nutrient and water balances, suppressing pests and diseases, changing nutrient and sediment loads, and the visual appearance of agricultural landscapes. With a few noted exceptions the evidence for the benefits of crop rotations comes from studies on one or two indicators of sustainability of specific management interventions and their impacts are measured in a single crop (mostly wheat) rather than over the whole cropping system. There is a need for context-specific evidence of the effects of different management interventions on a whole suite of aspects of sustainability and for minimizing negative impacts and dealing with trade-offs between competing sustainability imperatives over the whole crop rotation. Here we investigated the sustainability of 26 representative crop rotations in the subtropical grain zone by using quantitative indicators of economic and environmental sustainability (revenue, energy, protein, profit, risk, N applied, herbicide applications, NO3 leached, runoff, deep drainage and greenhouse gas (GHG) emissions) to investigate the sustainability of these rotations and the possibility of selecting rotations with efficient trade-offs between competing sustainability goals.

Methods

The study is based on cropping system simulation using the APSIM framework (APSIM Version 7.9; Holzworth et al. 2014) to simulate twenty-six rotations that were selected through focus groups of growers and consultants across the Northern Grain Zone of Australia to ascertain a wide range of crop rotations that are currently practiced by progressive growers in different locations (Hochman et al. 2020). These rotations have contrasting attributes in terms of their cropping intensity, crop types, crop diversity and their growing seasons.

Simulation outputs include yield, biomass, grain N, grain protein, N fertilizer applied, grain oil (canola), runoff, deep drainage beyond the root zone, NO3 leached beyond the root zone, number of fallow herbicide applications and greenhouse gas emissions (N2O plus net CO2 emissions as CO2 equivalents). Post simulation processing enabled calculation of additional outputs such as energy and protein using the USDA Nutrient Database for Standard Reference (Release 28, 2016) and revenue, profit (gross margins expressed in $/ha/yr) and risk (expressed as the gross margin exceeded in 80% of years) using median commodity prices (adjusted for inflation, transportation, grading or bagging costs) for the years 2008-2017 (Zull et al. 2020). We derived sustainability polygons to provide a visual representation of production and environmental sustainability attributes of different rotations at representative locations in the subtropical cropping zone. Each sustainability indicator is represented by a scaled (normalized) value where the most desirable outcome (e.g., highest profit or lowest GHG emissions) is represented at the outside edge of the polygon while the least desirable outcome is represented towards the centre of the polygon. The methods of this study are described in greater detail in Hochman et al. (2021).

Results



Rotation	Coded Description	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
A	xCaxWh	Fallow	Canola	Fallow	Wheat										
B	xWhxWhxCa	Fallow	Wheat	Fallow	Wheat	Fallow	Canola								
C	xWhxWhxCh	Fallow	Wheat	Fallow	Wheat	Fallow	Chickpea								
D	SoxMgWhxCh	Sorghum	Fallow	Mungbean	Wheat	Fallow	Chickpea								
E	SoChxWhxx	Sorghum	Chickpea	Fallow	Wheat	Fallow	Fallow								
F	SoChxWhMgx	Sorghum	Chickpea	Fallow	Wheat	Mungbean	Fallow								
G	xWhxChxWhxCa	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Fallow	Canola						
H	xWhxChxWhMgx	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Mungbean	Fallow						
I	SoxSoChxWhxx	Sorghum	Fallow	Sorghum	Chickpea	Fallow	Wheat	Fallow	Fallow						
J	SoxSoxSoChxx	Sorghum	Fallow	Sorghum	Fallow	Sorghum	Chickpea	Fallow	Fallow						
K	SoxSoxMgWhxx	Sorghum	Fallow	Sorghum	Fallow	Mungbean	Wheat	Fallow	Fallow						
L	SoxxChxWhxx	Sorghum	Fallow	Fallow	Chickpea	Fallow	Wheat	Fallow	Fallow						
M	SoxxWhxWhxx	Sorghum	Fallow	Fallow	Wheat	Fallow	Wheat	Fallow	Fallow						
N	xWhxxxChxx	Fallow	Wheat	Fallow	Fallow	Fallow	Chickpea	Fallow	Fallow						
O	xWhxBaxWhxCa	Fallow	Wheat	Fallow	Barley	Fallow	Wheat	Fallow	Canola						
P	xWhxBaxChxCa	Fallow	Wheat	Fallow	Barley	Fallow	Chickpea	Fallow	Canola						
Q	xWhxBaxWhxCh	Fallow	Wheat	Fallow	Barley	Fallow	Wheat	Fallow	Chickpea						
R	SoxxWhxChxWhxx	Sorghum	Fallow	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Fallow	Fallow				
S	SoxxWhxChxWhMgx	Sorghum	Fallow	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Mungbean	Fallow				
T	SoxSoxSoChxWhxx	Sorghum	Fallow	Sorghum	Fallow	Sorghum	Chickpea	Fallow	Wheat	Fallow	Fallow				
U	SoxSoxSoxxWhMgx	Sorghum	Fallow	Sorghum	Fallow	Sorghum	Fallow	Fallow	Wheat	Mungbean	Fallow				
V	SoxxChxWhxChxWhxx	Sorghum	Fallow	Fallow	Chickpea	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Fallow	Fallow		
W	SoxxChxWhxFbxWhxx	Sorghum	Fallow	Fallow	Chickpea	Fallow	Wheat	Fallow	Fababean	Fallow	Wheat	Fallow	Fallow		
X	SoxSoxSoxxChxWhxx	Sorghum	Fallow	Sorghum	Fallow	Sorghum	Fallow	Fallow	Chickpea	Fallow	Wheat	Fallow	Fallow		
Y	xWhxWhxBaxChxWhxCa	Fallow	Wheat	Fallow	Wheat	Fallow	Barley	Fallow	Chickpea	Fallow	Wheat	Fallow	Canola		
Z	SoxSoxSoFbxWhxChxWhxx	Sorghum	Fallow	Sorghum	Fallow	Sorghum	Fababean	Fallow	Wheat	Fallow	Chickpea	Fallow	Wheat	Fallow	Fallow

according to their identifying letters (A to Z).

: x = Fallow (~6 months), Ba = Barley, Ca =
So = Sorghum and Wh = wheat.

The sustainability polygons (Figure 1) illustrate the various productivity and environmental attributes of different rotations. At each of the four sites we selected for comparison three rotations that were identified as efficient trade-offs between profit and risk (Hochman et al. 2020). Any other rotations could be chosen for representation in these polygons but more than 3 rotations per polygon cause some degree of visual overload. For Gunnedah, a favourable cropping environment, the most profitable rotation (D; sorghum/fallow/mungbean/wheat/ fallow/chickpea) is also most favourable in terms of revenue, drainage and herbicide use. It is near best for runoff, energy produced, and N leached and intermediate for protein produced but is less favourable than the other two rotations (C and N) in terms of N applied, and downside risk and is equal second in terms of greenhouse gas emissions. Rotation choice at any site will depend on value- based weights ascribed to sustainability indicators and the weights ascribed to each indicator may well vary between different stakeholders. If equal weights are assumed, rotation F covers a greater area at the Gunnedah site and as such it might be considered the most sustainable. Without going into a detailed description of the remaining sites, Figure 1 illustrates that there are always trade-offs between some desired attributes. It also shows the difference between sites in the overall sustainability of any crop rotation and in which of the rotations are the most sustainable. There doesn’t seem to be an easy shortcut to estimating the most sustainable rotation as this will vary by location and soil type as well as the subjective weighting that is applied to different indicators.

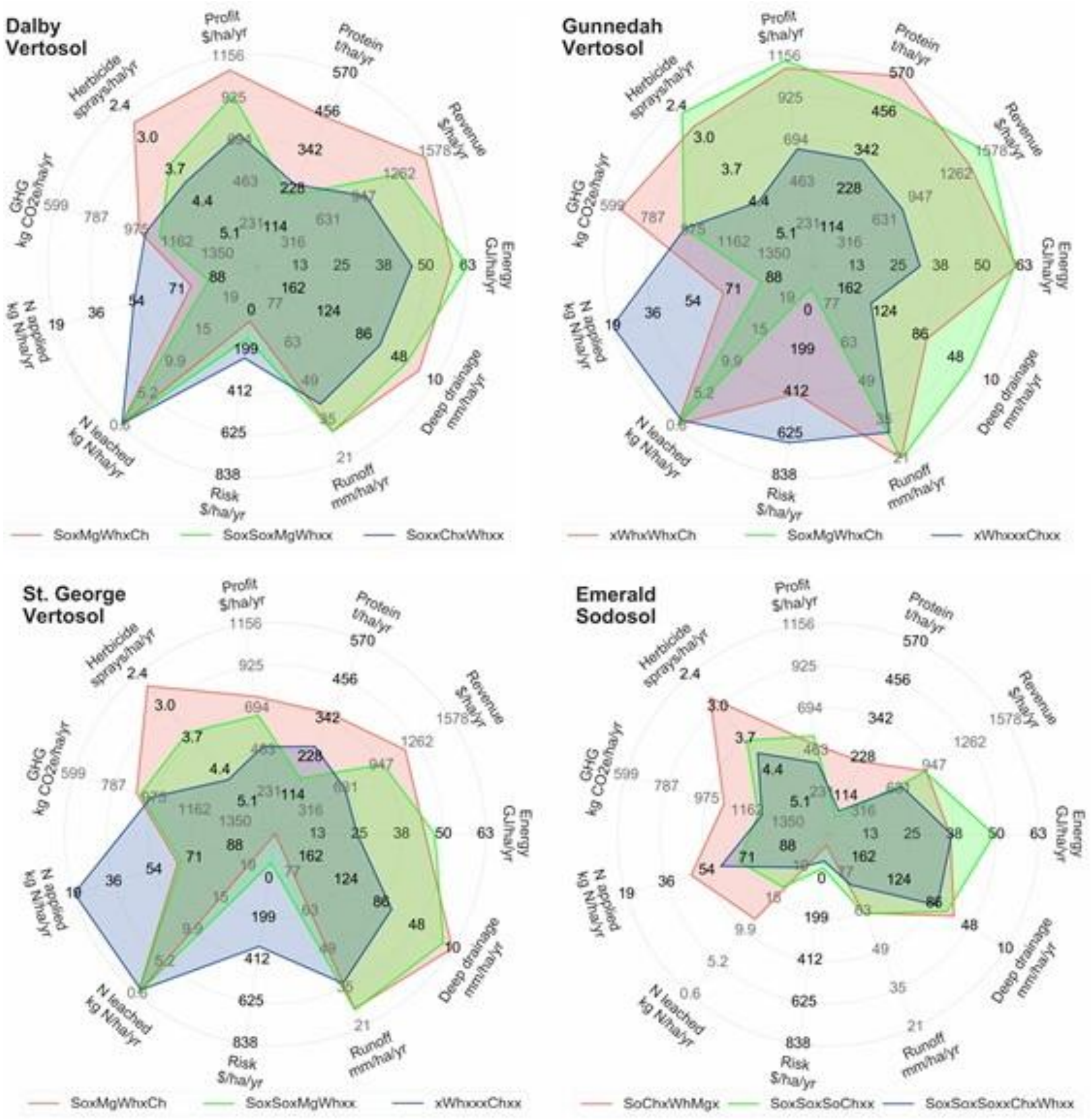


Figure 2. Efficient trade-offs between profit and GHG emissions on four contrasting sites.

Conclusion

Rotation choice has large implications on the sustainability of cropping in the subtropical grain zone. Sustainability polygons offer a visualization tool for appreciating the trade-offs that must be considered when selecting the most sustainable rotation at any location. Clearly, the perfect rotation for the subtropical cropping zone does not exist. However, in contrast with the oft-stated assumption of a negative association between intensification and sustainability of agriculture, this work demonstrates that the more profitable rotations were invariably among those that minimised the environmental impacts. We propose that these sustainability polygons and trade-off charts can serve as boundary objects for discussions between producers, advisers, researchers and other stakeholders interested in achieving the sustainable intensification of cropping systems.

References

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