Suboptimal crop rotations account for a 17% system revenue gap across dryland subtropical Australia

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Abstract

Little is known about yield gaps at the whole farm or regional level. To determine whole farm water-limited productivity in dryland subtropical Australia, we simulated 26 locally practiced crop rotations for over 800 weather stations by up to 3 soil types per station over 30-35 years by 2-7 fields per rotation for each site. We calculated and mapped the optimal results in terms of revenue per hectare per year over the cropping zone and compared results to those for each statistical local area (SA2). We found a relative revenue of 34% which is 17% lower than expected from the relative yields achieved by all the individual crops. We showed that intensive and diverse rotations tend to be the most productive and most profitable but may be too risky for many growers. Our research emphasises the importance of researching yield gaps of farming systems rather than individual crops.

Keywords

System yield gaps, Crop sequences, sustainable intensification, simulation, trade-off analysis.

Introduction

Yield gap analyses of individual crops have been used to identify opportunities for sustainable intensification of crop production at field to global scales. Standard protocols such as those of the Global Yield Gap Atlas (www.yieldgap.org) and Yield Gap Australia (www.yieldgapaustralia.com) are predicated on a crop by crop basis. The yield gaps of major crops in Australia have been mapped with an assumed cropping intensity of one crop per year. However, little work has been carried out to understand the impact of farmers' crop rotations on the yield gap at a whole farm or landscape scale. In an earlier study, a yield frontier analysis of data from a detailed longitudinal survey of 94 farmers' fields over 7 seasons in Australia's subtropical grain zone showed that while revenue from 36% of the individual crops in the study was found to be more than 80% of their production frontier values, only 29% of whole crop rotations achieved this benchmark. This was an indication that attention should be focused on the intensity and configuration of crop rotations and on the management of fallows in addition to the management of individual crops (Hochman et al. 2014).

To date there has been no attempt to map system yield potential (water-limited yield), actual system yields and system yield gaps at regional or national scale. Here we present a cropping system yield gap analysis of the Subtropical Grain Zone of Australia. This region takes in central and southern Queensland through to northern New South Wales as far south as Dubbo. Rainfall in this northern region tends to be summer dominant, allowing for dryland summer cropping, but with the high moisture-storing capacity of the clay-based soils of this region, supplemented by some winter rainfall, crops that grow during the winter are also successfully produced.

We expressed the system yield gap by comparing farmers' actual output data (sourced from ABARES and ABS) on total revenue obtained from the production of all crops per Statistical Local Area (SA2), with the simulated revenue surface created from the rotation with the highest revenue of 26 representative rotations at each of the weather stations and soil types in the cropping land use areas of the same SA2s. Additionally, we compared rotations' profit and risk to gain insights into why growers may choose crop rotations that result in less than optimal revenue.

Methods

Crop rotations vary in their system complexity (number of different crops in a rotation), cropping intensity (crops per year in a rotation), crop types (cereals, pulses, oil crops) and growing season (summer or winter crops). Rotations also need to accommodate considerations of weed and disease management as well as the logistic limitations imposed by labour and capital requirements. With a choice of seven major crops and various combinations of fallow periods between crops the possible permutations that can make up crop rotations is too numerous to analyse. Here we analysed 26 crop rotations, selected after consultation with 6 local groups of growers and agronomy advisers, that are practiced in various locations across the Northern Grain Zone of Australia.

To determine water-limited yields of the selected rotations, we conducted simulations using the Agricultural Production Systems sIMulator (APSIM Version 7.9; Holzworth et al. 2014) with historical temperature, rainfall and solar radiation data for 858 Bureau of Meteorology weather stations from SILO. For each weather station we selected the three most common soil types from the ASRIS map in the cropping land use class within a 20 km radius of each weather station. Soil profile characteristics for simulation of each soil type were determined (as described by Hochman et al. 2016) by taking the median value of the parameters of the same soil type from the 434 deep soil profiles characterised in the APSoil database (https://www.apsim.info/apsim-model/apsoil/). The simulations of all Crop rotations were phased, so that each field and year of the rotation was exposed to each year of the climate record. This allowed us to simulate an idealised farm or at least that part of the farm dedicated to rainfed cropping for each rotation by location by soil type combination. Simulations were then run, without retting soil parameters, for at least 30 years to capture the full range of climate variability. Best management practice rules were applied to the management of individual crops in the rotations. Here we focus on revenue profit (gross margin) and profit at risk, defined as the gross margin that is exceeded four in five years. Losses due to waterlogging, heat or frost shock events, disease, pests, weeds or crop nutrition other than nitrogen were not considered in these simulations.

Actual system yields were calculated from yearly agricultural statistics published by the Australian Bureau of Statistics from 1985 (ABS, 2019). The data contains estimates of tonnes produced, area sown, and yield by commodity (i.e. crop type) and statistical area. We aggregated the annual data of all field crops produced in each statistical area (SA2) to determine the actual total farm production from all crops per SA2 per year. Actual yield values were converted to revenue using median commodity prices (adjusted for inflation, transportation, grading or bagging costs) between 2008-2017 (Zull et al. 2020).

The simulated yields were converted to revenue and gross margin per rotation at each weather station and aggregated to a single value per year by weighting them in proportion to the area of each soil within a 20 km radius of each weather station. The weather station's water-limited yield (Yw) values were interpolated over the whole cereal land use surface of subtropical Australia using local variogram kriging over the grain cropping land use areas of the subtropical grain zone within the National Land Use of Australia (ABARE-BRS, 2010) map at approximately 1 km pixel size, using the gstat R package. These values were then aggregated up to SA2 level for comparison with the annual average yield (Ya) values available for each SA2. Thus, the independently estimated annual Ya and Yw (revenue) values per SA2 could be compared and the system revenue yield gap (Yw-Ya) and the system relative revenue yield (Y% = 100 x Ya/Yw) were calculated and mapped. These values were then compared to the actual production values (ABS 2019) of all dryland field crops grown at each SA2 for each of the production attributes so that results can be expressed as revenue or profit per SA2 per year. The 28-year average difference between the simulated value and the actual value at each SA2 is the system revenue yield gap for that SA2. The methods of this study are described in greater detail in Hochman et al. (2021).

Results

The twenty-six rotations exhibited a considerable degree of diversity in terms of the levers available to growers in designing these rotations. Cropping intensity had a range of 0.5 to 1.33 crops per year per rotation; Crop diversity had a range of 2 to 4 crops per rotation. Winter crops mostly dominated over summer crops with a range of 20% to 100% per rotation. Cereal crops (wheat, sorghum, and barley) made up 50% to 100% per rotation. Pulse crops (chickpea, fababean, and mungbean) made up 0% to 50% per rotation while oil crops (canola) made up 0% to 50% per rotation.

System Productivity

The maximum water-limited average annual revenue varied spatially from 717-2,260 $/ha/yr and only 3 different rotations dominated across all locations. The sorghum/fallow/mungbean/wheat/fallow/chickpea rotation (4 crops in 3 years) was dominant over most of the subtropical cropping zone. We mapped actual system revenue (Figure 1a), potential system revenue (Figure 1b), the gap between them (Figure 1c), and the relative system revenue gap (Figure 1d) at SA2 resolution. The average (area-weighted) revenue achieved over the subtropical grain zone was 487 $/ha/yr, while the weighted average revenue of the water-limited systems was 1,457 $/ha/yr. This is a revenue gap of 970 $/ha/yr and a relative revenue of 34%, compared to relative yields of 40% to 60% for a range of individual crops in the subtropical grain zone (www.yieldgapaustralia.com). Importantly, this result shows that system gaps are substantially larger than that implied by the sum of yield gaps of individual crops.

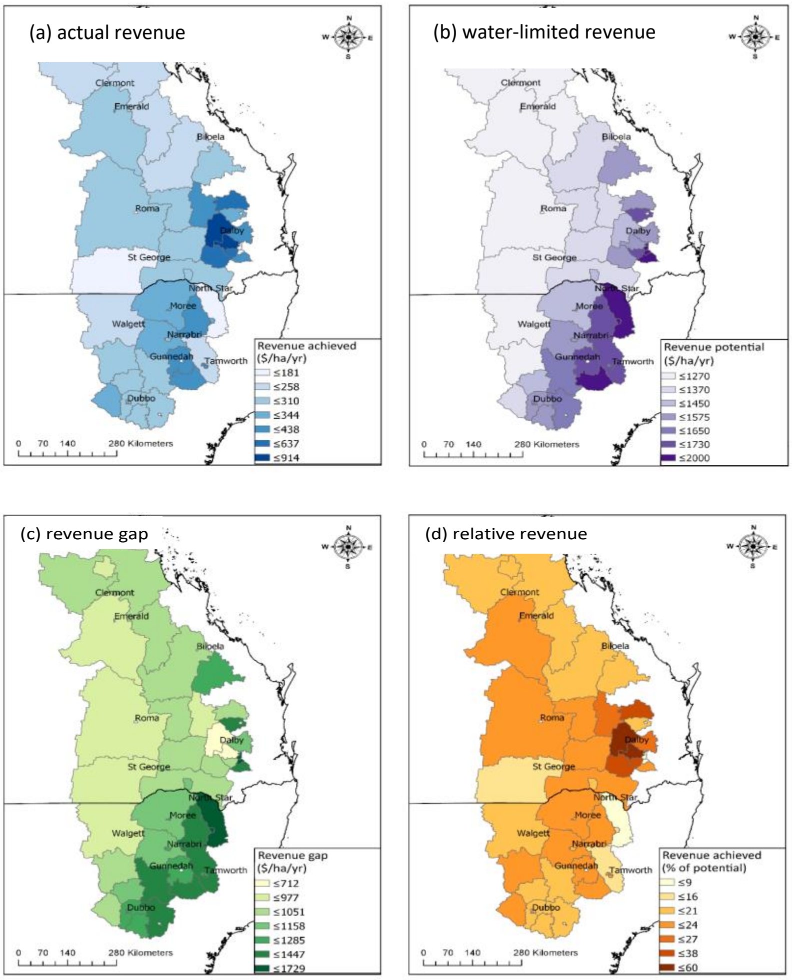

Figure 1. System average annual revenue gaps ($/ha/yr) at SA2 resolution: (a) actual revenue (b) water-limited potential revenue, (c) the gap between actual and potential revenues and (d) relative revenue, or actual revenue expressed as a percentage of the water-limited revenue.

The Role of Profit and Risk Aversion in System Yield Gaps

While energy and protein production are imperatives for global food security, producers who are the decision makers choosing between these rotations, are more interested in maximizing profit while minimizing financial risk. While an “economically rational, profit maximizing” grower would always choose the rotation that is the most profitable on average, the highly variable climate in the subtropical cropping zone justifies a certain amount of risk aversion. In Figure 2 we present, for each of the 26 rotations, plots of their average profit against risk, expressed as the profit that they exceeded in the poorest 20% of years, at three illustrative sites. For most sites investigated, D was the most profitable rotation but also among the riskiest. Rotation N was often the least risky but also the least profitable on average. An interesting exception was rotation J, the sorghum/fallow/sorghum/fallow/sorghum/chickpea/long fallow rotation (4 crops in 4 years) on a Sodosol at the Emerald site where it was both the most profitable and the least risky rotation. Rotation J is the optimal ("win-win") rotation at that site. For all other sites, profit-risk trade-offs must be made. For any given site in Figure 2, an efficient trade-off between profit and risk is made when moving from the highest (most profitable) point down to the next highest point to its right (less risky) along the broken line which represents a profit-risk efficiency frontier. All points below this frontier represent rotations with less efficient profit-risk trade-offs. Rotations below the frontier are less profitable and riskier than alternatives on the frontier. The choice between rotations on the efficiency frontier reflect the grower's risk preference. Moving from rotation D to rotation C at the Dubbo site involve a small loss in average profit in exchange for a larger gain in the profit of the 20% least profitable crops. Such a trade-off might be attractive to a moderately risk averse grower. By way of contrast, moving from rotation D to rotation C at the North Star site involves a much greater loss in average profit for a similar gain in the profit of the 20% least profitable crops. This option may be attractive to a more risk averse grower.

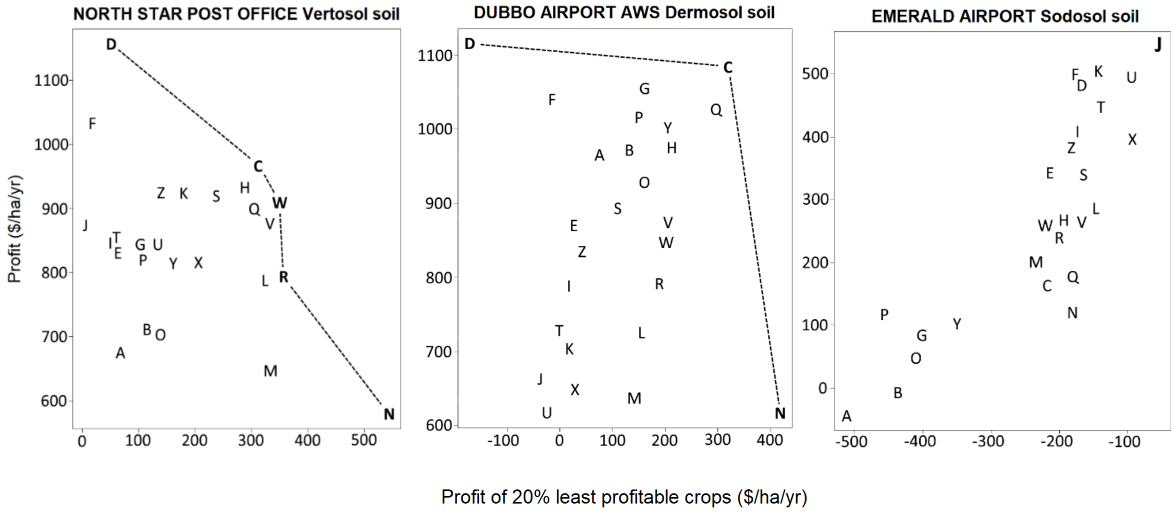

Figure 2. Profit–Risk trade-offs at 3 sites. Letters joined by a broken line denote rotations that most efficiently trade-off between the objectives of maximizing profit and minimizing risk.

Conclusion

A focus on systems yield gaps has revealed the importance of rotations for maximizing farm revenue in the subtropical cropping zone. Profit-risk tradeoff analysis showed that well informed and agronomically skilled growers who are risk averse may well choose rotations that are less productive than those with the highest revenue. It is also likely that lack of knowledge about which are the most efficient rotations, lack of access to credit and lack of skill to execute these rotations according to best management practice, are additional factors behind the systems yield gaps quantified in this study.

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