Farm optimisation modelling to improve rotation choice on a mixed enterprise farm in a variable environment

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Key messages

- Selecting the 'best' suite of rotations to apply on a farm is complex. This analysis considers ~3500 different rotation phases.
- Tactically adjusting rotation choice in response to unfolding weather conditions increases farm profit by 6% for the most profitable type of weather-year and 23% for the least profitable type of weather-year
- The most important tactical adjustment is to canola area, varying by up to 63%, in response to unfolding weather conditions; but there are scores of other tactical decisions made, that in combination, also boost farm profit.

Aims

1. Identify optimal rotation selections for a typical mixed enterprise farm business in the Great Southern region.
2. Quantify the financial importance of making tactical rotation decisions as the year unfolds.
3. Demonstrate the use of AFO; an improved whole farm optimisation model.

Introduction

Rotation decisions are a complex aspect of farm planning. There are many different land use options and sub options which have varying effects on soil condition, pest and disease prevalence and weed seed banks, and affect crop and animal production costs and revenues. For example, triazene-tolerant canola needs to be considered separately to a Roundup Ready canola and a spray topped pasture needs to be considered separately to a naturally senesced pasture. A further complication is that current paddock condition can be affected by land use choice and management up to 5 years ago. For example, the weed and pasture seed bank can be affected by land use choice 4 or 5 years prior (Monjardino et al., 2004). Soil nutrient level and disease prevalence is affected by paddock land use over the preceding 2 or 3 years or longer (Dixon and Tilston, 2010, Brooks et al., 2018). Factoring in all these components quickly makes rotation planning a large and complicated task, especially with the overlay of changing input and commodity prices.

A further complication of rotation choice is Australia's highly variable climate, which results in significant production and profit variability (Feng et al., 2022, Laurie et al., 2018, Trompf et al., 2014). Kingwell et al. (1992) showed that weather and price variations have significant effects on optimal farm management and profitability. To handle the volatile nature of farming, farmers can alter their "big-picture" strategic management to set up a more flexible business and farmers can implement short term tactical adjustments in response to unfolding conditions (Anderson et al., 2020).

Most previous farm management research has assumed that every year is the same (Bathgate et al., 2009, Kopke et al., 2008, Young et al., 2010, Young et al., 2020) or when year-to-year variation has been included, management has not been optimised and frequently the tactical management options considered have been over simplified (Godfrey et al., 2019, McGrath et al., 2016).

In this paper we overcome previous limitations by applying an improved optimisation model with a detailed representation of year-to-year variation and an extensive array of tactical management options, to identify and quantify optimal rotation management.

Method

A model called **A**ustralian **F**arm **O**ptimisation (AFO) has been applied in this analysis. AFO is a whole farm linear programming model that supersedes the historically popular MIDAS model (Bathgate et al., 2009, Kingwell, 2011, Kingwell and Pannell, 1987, Kopke et al., 2008, Pannell, 1996, Thamo et al., 2013, Young et al., 2011, Young et al., 2020). The model represents the economic and biological details of a farming system, including modules for rotations, crops, pastures, sheep, crop residue, supplementary feeding, machinery, labour and finance. Furthermore, it includes land heterogeneity by considering enterprise rotations on any number of soil classes or land management units (LMU). AFO is designed to usefully evaluate rotation choices. Firstly, AFO has a detailed and flexible rotation module that includes rotation phases up to 5 years in duration with 3827 cumulative rotation phase options. Secondly, AFO includes year-to-year climate variation and a large range of tactical management options including altering land use choice, altering the timing of operations, reseeding, hiring contractors, converting crops to standing fodder or hay, altering stock nutrition profile, undertaking early season crop grazing and adjusting stock sale timing. Thirdly, AFO includes powerful stock and feed budgeting modules which are an important aspect of rotation decision making in a mixed farming system. Finally, AFO leverages powerful solving algorithms that efficiently identify optimal management for a given farm system.

For more description of AFO see the model documentation: https://australian-farm-optimising-model.readthedocs.io/en/latest/index.html.

The farm system modelled by AFO is a typical farm in the Great Southern region of Western Australia. It is a farming system comprising a mix of crop and livestock enterprises, a 6-month growing season and receiving between 400 and 550 mm of annual rainfall, mostly in the growing season. The farm is 2130 ha and includes three land management units (LMU) (Table 1). The calibration of crop and pasture inputs was completed through a combination of simulation modelling and consultation with regional experts. The cropping enterprise represented is a high input high output system typical of current practices.

The growth rate of the pastures and crop yields in each rotation in each weather-year (Table 2) represented were generated using AusFarm simulation modelling (Moore et al., 2007) and information provided by a local agronomist. Climate data was sourced from the Kojonup weather station over the period from 1970 to 2020. Soil data representing the LMUs was sourced from existing data in the APSOIL database (Dalgliesh et al., 2012). Other key features of the modelled farm are shown in Table 1.

Table 1: Key features of the modelled farm.

Farm size (ha)	2130
LMU 2: Deep sands but not waterlogged	150
LMU 3: Gravels or sandy gravels over clay	1230
LMU 4: Sandy loams over clay	750
Time of lambing	Spring lambing
Pregnancy scanning management	Scanning for pregnancy status only
Sheep liveweight	Nutrition profile is optimised by AFO
Sheep genetics	Medium frame merino
Standard reference weight (kg)	55
Fibre diameter (μ)	20
Canola Yield (t/ha)[1]	
Roundup-ready	2.6
Standard	2.2
Wheat Yield (t/ha) [1]	4.5
Barley Yield (t/ha)[1]	5.0
Oat Yield (t/ha) [1]	4.5
Hay Yield (t/ha) [1]	8.0
Lupin Yield (t/ha) [1]	2.5
Faba bean Yield (t/ha) [1]	3.0

[1] Reported yield is on LMU 4 (best-performing areas of the farm) in a canola–cereal or pulse-cereal rotation weighted across all weather-years.

Table 2: AFO Kojonup weather-years for the current climate

Code for weather-year	Definition of each weather-year	Probability of occurrence	Growing season rainfall	Crop yield scalar[4]
z0	Early break[1] with follow up rains and a good spring[3].	24%	447	1.2
z1	Early break with follow up rains and a poor spring.	20%	346	1.0
z2	Early break that turns out to be a false break[2] but is followed up with a good spring.	8%	416	1.22
z3	Early break that turns out to be a false break and is followed by a poor spring.	4%	294	0.87
z4	Medium break with follow up rains and a good spring.	14%	448	1.05
z5	Medium break with follow up rains and a poor spring.	16%	392	0.83
z6	Late break with follow up rains and a good spring.	4%	477	0.95
z7	Late break with follow up rains and a poor spring.	10%	337	0.65

[1] Early break (i.e. start of the growing season): before the 5th May; Medium break: between the 5th May and 25th May; Late break: after the 25th May.
[2] False break: pasture feed on offer reaches 500 kg/ha followed by 3 weeks of no growth.
[3] Good spring: above the median (86mm) rainfall for September and October; Poor spring: below the median rainfall.
[4] Yield scalar is the relationship between yield in the given weather-year and the average yield. This was calculated using the output of APSIM modelling using Kojonup climate and soil data from 1970 - 2019.

Results

Tactically adjusting rotation choice in response to the unfolding weather conditions increases farm profit by 6% for the most profitable weather-year and 23% for the least profitable weather-year (

Table 3). In early break years it is optimal to increase canola area by 63% and in late break years it is optimal to decrease canola area by 56% (Table 4). All of the tactical adjustments occur on the productive soils (LMU 3 and LMU 4). Sandy soils (LMU 2) are never tactically adjusted, always remaining in continuous pasture. On LMU 3 (sandy gravels), where barley grew in the previous year, it is optimal to establish canola in years with an early break and follow up rains (i.e. weather-years z0 and z1. See Table 2). In early break years with no follow up rains (weather-years z2 and z3) it is optimal to follow 85% of the barley with canola and the remaining 15% with barley. In medium and late break years (z4 to z7) it is optimal to follow barley with wheat. The difference in rotation selection based on the presence or absence of follow up rains in early breaks shows that in years with an early break it is optimal to delay the rotation decision on a proportion of the area until follow-up rains are received. On LMU 4 (sandy loam), when the season breaks early and has follow up rains it is optimal to establish canola on all areas that in the preceding year grew spray-topped pasture and on 46% of the area that had a non-manipulated annual pasture in the previous year. In all other years it is optimal to remain in annual pasture. Similar to above, the difference in rotation between early break years with and without follow up rains shows that it is optimal to delay the tactical decision to increase canola area until follow up rains occur.

For succinctness we report here on the land use tactic of seasonally adjusting the area of canola. However, in combination with choice of canola area are many other complementary tactical decisions not mentioned due to the need to be parsimonious. One illustration of complementary tactics is that, in the examined scenario, it is optimal to reseed a proportion of pasture after false breaks and dry seed wheat and canola in late break years.

AFO can undertake a wide range of sensitivity analysis, for example, changing the probability of the weather-years to represent a drier climate. Such analyses using AFO show that in a drier climate it is optimal to increase the area of fodder crops in cropping programmes.

Table 3: Key descriptors of the optimal farm plans with and without tactical rotation changes for a typical Kojonup farm.

	With rotation tactics	Without rotation tactics
Farm profit ($/year)		
Expected[a]	863 434	833 027
Max[b]	1 308 751	1 234 952
Min[c]	153 600	125 009
Pasture (% of farm area)		
Expected	38	35
Max	46	35
Min	33	35
Cereal (% of farm area)		
Expected	38	45
Max	52	45
Min	28	45
Canola (% of farm area)		
Expected	24	20
Max	39	20
Min	9	20

[a] 'Expected' is the weighted average of all weather-years., [b] 'Max' is the maximum across the weather-years. [c] 'Min' is the minimum across the weather-years.

Table 4: Optimal land use area (hectares) in each weather-year

Weather-year	Pasture			Cereal			Canola		
	lmu2	lmu3	lmu4	lmu2	lmu3	lmu4	lmu2	lmu3	lmu4
z0	150	98	451	0	535	68	0	598	230
z1	150	98	451	0	535	68	0	598	230
z2	150	101	556	0	592	184	0	537	10
z3	150	101	556	0	592	184	0	537	10
z4	150	154	681	0	902	56	0	174	13
z5	150	154	681	0	902	56	0	174	13

z6	150	107	540	0	951	157	0	172	53
z7	150	107	540	0	951	157	0	172	53

Conclusion

AFO is an advanced whole farm optimisation model that identifies the optimal suite of rotations and tactical rotational adjustments on a typical Great Southern farm. Modelling results indicate that tactically adjusting rotation choice in response to unfolding weather conditions increases farm profit by 6% for the most profitable type of weather-year and 23% for the least profitable type of weather-year. The major rotation tactics involve increasing canola area by up to 63% on productive soils in rotations following barley or spray-topped pasture, in early break seasons to capitalise on the longer growing season. Not reported are many additional complementary tactics.

AFO is a powerful tool for many different topics of farm analysis, not just rotation selection and rotational tactics within weather-years.

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