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An economic analysis of sheep flock structures for mixed enterprise Australian farm businesses

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A strategic question facing many mixed enterprise broadacre farm businesses in Australia is, 'What sheep flock size and structure is most profitable to complement the farm's cropping enterprises?' This study answers this question for a typical large mixed enterprise farm business in a key production region of Australia. Whole-farm bioeconomic modelling, combined with broad-ranging sensitivity analysis, is used to examine the profitability of different sheep flock structures and sizes. We find the most profitable flock structure is to run Merino ewes and turn off finished Merino or first-cross lambs. The profitable selection of these flocks is robust to commodity price variation but does require the farmer to give more attention to sheep management. The correct choice of flock structure greatly adds to farm profit. A farm based on cropping and a self-replacing Merino flock using surplus ewes for first-cross, meat lamb production earns 33 per cent more profit than a similar farm that runs a traditional self-replacing Merino flock that emphasises wool production. Of far less importance than flock structure, as a source of additional profit, is to increase flock size or adjust cropping intensity.

Key words: crop and livestock integration, farm modelling, flock structure, sheep, wool.

1. Introduction

Farming systems can be complex (Price and Goode 2009; Kingwell 2011), sometimes involving large areas with a range of soil types, and several crop, pasture and livestock enterprise choices. These enterprises are all subject to price and climate variability, and often are reliant on relatively inflexible infrastructure (Ewing and Flugge 2004). Such complexity complicates decision-making, and even with access to data and information about each of these factors, decision-making still remains a challenge (Pannell 1996). The size and intricacies of farms, combined with farmers often being time poor, means farmers often have limited opportunity to evaluate the strategic direction of their farm businesses and fully plan their operations. Hence,

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farmers tend to turn to professional advisers to aid them in business planning, especially when the business needs to generate profit in order to maintain or enhance business viability (Pannell 1996).

Farm advisers tend to use simple decision-making tools such as whole-farm budgets, partial-farm budgets and gross margins (Dent *et al.* 1986). These techniques offer a quick and affordable way to evaluate farm strategies and plans but often fail to accurately capture important aspects, such as biological interactions between enterprises and technical detail such as soil type. An alternative to the fairly simple appraisal techniques used by many farm management advisers is to opt for detailed whole-farm optimisation modelling (Kingwell *et al.* 1995; Kopke *et al.* 2008). Whole-farm modelling provides a detailed representation of the whole-farm system, including its various resources of finance, soils, labour, machinery, livestock, crops and pastures.

Representing the whole farm allows the interactions within a farm system to be accounted for, which is important when assessing farm strategy because many aspects of the farm system are interrelated and changing one factor may affect another (Villano *et al.* 2010; Archer *et al.* 2019). Examples of interactions between the livestock and crop enterprises on mixed farms include the following: grazing of stubble residues by livestock after harvest, the impact of crop on the pasture seed bank available for subsequent pasture regeneration, the fixing of atmospheric nitrogen by pasture legumes used by subsequent crops, and alternative weed control options available in a pasture phase that can reduce the weed burden or weed spectrum in subsequent crops. Each of these interactions may influence optimal rotation selection and livestock management; hence, it is important to consider the integration between the livestock and cropping operations when evaluating the profitability of alternate strategies on mixed enterprise farms.

In the mixed livestock and crop farming regions of Australia, often the main livestock operation is sheep production. There are two key outputs from sheep production: wool and sheep sales (Keogh *et al.* 2016). A range of flock options can be employed by farmers, which generate varying levels of these outputs. One traditional flock option is to focus on wool production with a Merino wether dominant flock. Another option is to focus on meat production by introducing alternate breeds and selling finished prime lambs. Other alternatives are a joint focus on meat and wool.

The Australian sheep industry was founded on wool production from Merino sheep (Keogh *et al.* 2016). However, since the collapse of the Australian wool reserve price scheme in 1991, farmers have switched to a younger flock structure, turning off younger wethers and lambs (Martin 2004). This behaviour of farmers concurs with the findings of Kopke *et al.* (2008) who examined seven main sheep flock structures of interest to farmers in Western Australia. These researchers concluded that it was most profitable to produce first-cross lambs. The sheep systems they examined principally involved maintenance of either a pure Merino flock or the introduction of terminal meat breed rams to generate lambs more suited to finishing as a prime lamb. However, their analysis did not assess the profitability of a trade wether flock or a maternal flock consisting of sheep with a different genotype that increased reproductive performance. Moreover, in the decade since the study of Kopke *et al*. (2008), there have been significant improvements in crop yields and cropping technologies due to improved genetics and new innovations (Robertson *et al*. 2016). In addition, the study by Kopke *et al*. (2008) occurred in a period when commodity prices were much lower than they are currently and Australia's sheep population was over 10 per cent higher than it is currently (MLA 2019). In fact, only in the years preceding 1886 and in the year 1905 has Australia's sheep population been smaller (ABS 2013) than is the case in 2020.

Data from MLA show the weighted average price for lamb (22.1–24 kg carcass weight (cwt)) in Western Australia during 2019 was 733 c/kg cwt (Meat and Livestock Australia 2020) and the eastern market indicator wool price during 2019 was mostly above 1,600 c/kg clean (Landmark 2020). By contrast, the prices used by Kopke *et al*. (2008) were 900 c/kg clean for wool and 300 c/kg cwt for lamb. Measured on a carcass weight basis, lamb is currently the most expensive of the main meats consumed in Australia (ABARES 2018a). Other changes in commodity prices since the Kopke *et al*. study include wheat, the main crop grown on Australian mixed enterprise farms. Its price in 2008/9 versus 2017/18 was $US236 and $US223 per tonne, respectively (ABARES 2018a). Given these price relativities, many farmers now wonder what flock size and structure best serves the profitability of their farming business.

To help address the question of what structure and size of sheep flock can best serve the profit interests of mixed enterprise farms in Australia, this study applies whole-farm bioeconomic modelling. In a study region in the south-west of the Western Australian grainbelt, we examine how different sheep flock structures and sizes of the sheep flock affect farm profitability, farm management and business strategy. Using whole-farm bioeconomic modelling and wide-ranging sensitivity analyses, we test the hypothesis that whole-farm profit is sensitive to flock structure.

The next section outlines the research methodology, followed by presentation of modelling results and sensitivity analyses. After a discussion of these results, some conclusions are drawn.

2. Research methodology

2.1 The model

2.1.1 Nature of the model

The whole-farm model employed in this analysis is known as Model of an Integrated Dryland Agricultural System (MIDAS), originally developed and described by Kingwell and Pannell (1987). Since its inception, MIDAS has been expanded and updated regularly by various researchers to consider a range of farming system issues in various regions, notably Finlayson *et al.* (2012), Flugge and Schilizzi (2003), Gibson *et al.* (2008), Thamo *et al.* (2013), Young *et al.* (2011) and Young *et al.* (2010). The model is a whole-farm linear programming model with a joint emphasis on biology and economics (Pannell 1996). The model comprises components for crops, pastures, sheep, stubble, grain feeding, machinery, labour and finance. It also includes land heterogeneity by considering enterprise rotations on up to nine soil classes (Kingwell 2011). The model's objective function is the maximisation of year-in-year-out (or steady state) farm profit, generated by selecting the optimal suite of activities whilst honouring constraints on resource availability (Kopke *et al.* 2008).

2.1.2 Rationale

Model of an Integrated Dryland Agricultural System can evaluate the economic significance of alternative farm strategies, in a steady-state format, by revealing farm management decisions that maximise whole-farm profit under a given set of constraints, with a range of production possibilities and enterprise interactions that typify the strategy being examined. For example, the model describes the biology of farm production in sufficient detail to allow the profitability and value of different flock structures and flock sizes to be evaluated. The nutrition requirements of each age and type of sheep throughout a production cycle are described, as is the range of feed sources that can be utilised to match those requirements. The effect of stocking rate on pasture production is also considered within the model, along with the sale prices associated with the wool and meat produced by each type of flock structure.

2.1.3 Model version

The Great Southern regional version of the MIDAS suite of models was used for this analysis. This version has been used previously for analysis of crop profitability (Poole *et al.* 2002) and livestock profitability (Young *et al.* 2011).

The Great Southern regional version of MIDAS represents an average farm in the Great Southern region of Western Australia. However, in this study, the model was tailored to represent a larger farm business in the south-west of the Western Australian grainbelt. The owners and managers of the farm were willing and able to supply detailed farm data that facilitated the accurate portrayal of their farm business. Therefore the results from this study are not only highly relevant to that particular farm, but are also to similar farms in the region. The region contains approximately 11 per cent of the Western Australian sheep flock and comprises approximately 380 farms occupying a total of 711,000 ha (ABARES 2016).

2.1.4 Model calibration

To calibrate this version of MIDAS, input data were altered to represent the technical management and characteristics of the focus farm. Actual farm data were used to specify the mix of soils, land area, crop yield relativities, pasture production, sheep genotype and production, labour availability, machinery investment and work rates. The process of model construction and calibration occurred over several months in close collaboration with the farm manager, ensuring the model accurately portrayed the farm business.

The data to calibrate the model had been collected over a 10 year period. This enabled an average year to be described accurately. In turn, this implied the model's solution applied to an average year, facilitating medium-term farm planning. Additional details on the calibration of MIDAS are in Appendix S1.

2.1.5 Key features of the farm model

Table 1 lists the main characteristics of the farm model.

Table 2 lists the sheep flock structures analysed in this study. These different systems range from wool-focused production to specialist meat production and a mix of both meat and wool production. Within this table is the farm manager's current strategy, not identified due to commercial privacy concerns, as well as several other feasible options.

Tables 3 and 4 list the production parameters in the model for ewes and wethers in the different flocks.

Tables 5 and 6 list the baseline sheep and wool commodity prices used in the analysis.

2.2 Sensitivity analysis framework

The different flock structure options listed in Table 2 were compared using the baseline data parameters listed in the other tables. The optimum farm plan (stocking rate, level of grain feeding, crop area, rotation mix, etc) was

Table 1 Summary of the farm's key characteristics

Farm size (ha)	6,380
Area of crop (%)	59
Number of land management units (LMUs)	4
Canola yield (t/ha)†	2.2
Barley yield (t/ha)†	3.4
Oat yield (t/ha)†	3.8
Wheat yield (t/ha)†	3.1
Hay yield (t/ha)†	5.7
Labour (FTE)	8.1
Number of harvesters	1 (12.2 m front)
Seeding gear complements	1 (12.2 m width)

Note: †Note reported yield is on LMU 4 (best-performing areas of the farm in a canola–cereal rotation). FTE, full-time equivalent.

Table 2 A description of flock types included in this analysis

Flock	Description
Store	A self-replacing Merino flock with emphasis on wool production. Wethers are sold as store lambs to other farmers (6 months)
Export wether (shipper)	A self-replacing Merino flock with emphasis on wool production. Wethers are sold as shippers (18 months or older)
Merino prime lamb (MPL)	A self-replacing Merino flock with emphasis on wool and meat production. Includes all selling options contained in the preceding two flock options plus the additional option of selling finished Merino lambs (10 months)
Trade wether	Buy in-store wethers, sell them later as shippers (18 months or older). The emphasis is on wool production
Self-replacing crossbred lamb (SRF-MTS)	A self-replacing Merino flock utilising surplus ewes (cast for age or surplus ewe hoggets) for first-cross lamb production sold as suckers[†] (4.5 months). Merino wethers can be sold as Merino prime lamb or as shippers. The emphasis is on meat and wool production
Specialised crossbred lamb production (Specialist-MTS)	Replacement Merino ewes are bought in. All ewes are mated to produce first-cross lambs sold as suckers[†] (4.5 months). The emphasis is on meat and wool production
Composite	Composite ewes are mated to composite rams to produce composite lambs. Wethers are sold as suckers[†] (4 months), and the emphasis is on meat production

Note: [†]Lambs that are still dependent on their mothers for milk.

Table 3 Summary of the sheep class sale weights, wool cut and wool quality

Sheep class[†]	Live weight at Sale (kg)	Wool production (kg/hd)	Fibre diameter (μ)
Wether lamb (5 mo)	28	1.1	19.0
Wether hogget (17 mo)	47	2.4	17.4
Wether (29 mo)	58	3.3	18.5
Wether (41 mo)	60	4.2	20.5
Wether (53 mo)	61	3.9	20.7
Wether (65 mo)	63	3.5	20.6
MPL (10 mo)	41	2.1	18.4
MTS (sucker 4.5 mo)	41	–	–
Composite (sucker 4 mo)	42	–	–

Note: [†]The age at shearing and sale is in brackets. –, not shorn prior to selling; mo, month old.

determined for each flock structure. Then sensitivity analyses were conducted to examine the robustness of the findings. The parameters and variables subject to change were weaning weight, stocking rate, cropping level, wool and meat prices (Table 7) and grain prices (Table 8). The sensitivity analysis revealed the robustness of choice of particular flock structures and how vulnerable was farm profit to these changes.

Table 4 Summary of production from each sheep genotype

	Units	Sheep genotype		
		M – M	M – T	C – C
Time of lambing (TOL)[†]		Late July	Early June	Early June
Ewe wool production[‡]	kg/hd	3.5	3.5	2.5
Fibre diameter	μ	20.3	20.7	32.3
Lambing	%	92.3	98.4	118.6
Weaning age	mo	2.8	4.5	4.1
Weaning weight single[§]	kg	21	41	42

Note: C – C, composite ewe mated with composite ram; M – M, Merino ewe mated with Merino ram; M – T, Merino ewe mated with terminal sire. [†]TOL selected based on common practice. [‡]Average of age groups (2–6 year old) and birth type (single, twin and triple). [§]Weighted average of single, twin and triplet. mo, month old.

Table 5 Saleyard and the net on-farm prices of animal classes sold[†]

	Price of the main line of sheep sold		Average price net on-farm
	$/kg DW	$/hd	$/hd
Wether lamb (6 mo)	5.63	NA	64.7
MPL (10 mo)	6	NA	100.8
Wether hogget (17 mo)	NA	97	83.2
Wether (29 mo)	NA	95	80.6
Wether (41 mo)	NA	95	80.6
Wether (53 mo)	NA	90	77.6
Wether (65 mo)	NA	90	77.6
MTS (sucker 4.5 mo)	6.20	NA	97.6
Composite (sucker 4 mo)	6.20	NA	102.5

Note: [†]To form an on-farm price, account is taken of selling costs, transportation and an allowance for animals that are off-spec and thus sell for a lower price. DW, dressed weight; mo, month old; NA, Not applicable.

Table 6 Sheep classes' baseline wool prices and the price range for fibre diameter

Fibre diameter	Fleece price	Sweep-the-board price[†]	
μ	c/kg clean	c/kg clean	c/kg greasy
Merino lambs	813	689	482
XB lambs	675	568	397
18	2,062	1,766	1,130
19	1,831	1,565	1,002
20	1,626	1,387	888
21	1,500	1,283	821
22	1,415	1,209	774

Note: [†]The sweep-the-board price is lower than the fleece price as, at shearing, fleece wool is collected along with less valuable pieces, bellies and locks of wool.

Table 7 Sheep and wool prices used in the sensitivity analysis

	Lamb (\$/kg)[†]	Shipper (\$/hd)	Ewes (\$/hd)[‡]	Wool (c/kg)[§]
High (+20%)	7.20	114	102	1,800
Baseline	6.00	95	85	1,500
Low (−20%)	4.80	76	68	1,200

Note: [†]Merino prime lamb price. Wether lambs 6 months old sold to other graziers have a 37 c/kg discount, and crossbred lambs have a 20 c/kg premium. [‡]Price for a 5-year-old. Note, 6-year-olds are discounted \$15/hd and ewe hoggets have a \$20/hd premium. [§]Western market indicator price (c/kg) for clean 21 micron wool.

Table 8 Grain prices used in the sensitivity analysis (FOB \$/t)

	Wheat (\$/t)	Barley (\$/t)	Oats (\$/t)	Canola (\$/t)	Lupins (\$/t)
High (+20%)	354	354	282	648	366
Baseline	295	295	235	540	305
Low (−20%)	236	236	188	432	244

Weaning weights were reduced by up to 20 per cent, and the stocking rate was altered across a range of 30 per cent below through to 10 per cent above the optimum. A broad spectrum of cropping intensity also was considered, ranging from 20 per cent to 80 per cent of the farm area being committed to cropping.

3. Results

3.1 Flock comparison

Flocks based on Merino ewes, and selling finished Merino or first-cross lambs, were the most profitable (Figure 1). Importantly, these flock structures were over 20 per cent more profitable than flocks that retained wethers. A related main finding was the longer the wethers were retained, the lower was farm profit. The exceptions were the composite and store flocks. The composite flock was less profitable because the composite genotype did not produce the quality and quantity of wool of the pure Merino genotype. The store flock was less profitable because its lambs were sold at a lighter weight, thereby generating less sales income. Within the Merino flocks that sold finished lambs, revenue was increased by including terminal sires. Mating all Merino ewes to a terminal sire (Specialist-MTS) increased profit by 9 per cent, compared to mating only surplus ewes (SRF-MTS), and 15 per cent, compared to not mating any ewes to terminal sires (MPL).

Optimal farm management varied for the different flocks. Generally, the longer the wethers were retained, the lower was the proportion of ewes in the flock. As the proportion of ewes in the flock decreased, the stocking rate and

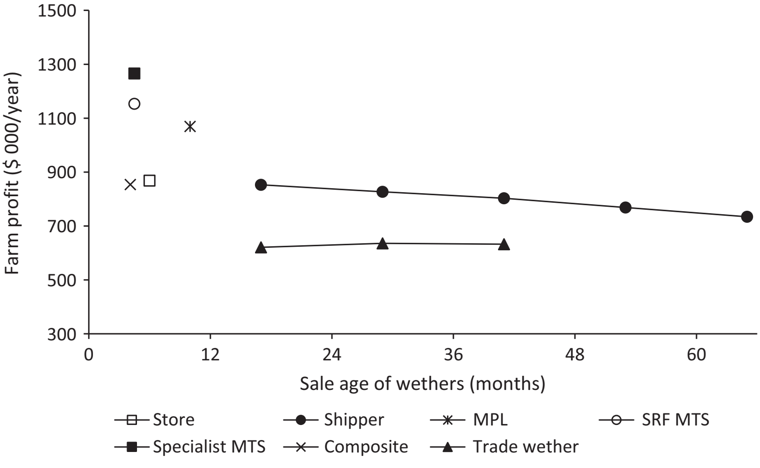

Figure 1 Whole-farm profit for each flock structure evaluated in this analysis.

supplementary feed also decreased. Flocks selling first-cross lambs had the highest stocking rates and supplementary feed requirements (Table 9).

Weaning weight had a large impact on the profitability of composite and MTS flocks (Figure 2). These flocks had a greater focus on meat production, and the lambs were sold at 4–4.5 months of age, so they required extra grain feeding to reach finishing weights if they were weaned at a lower weight. A 5 per cent reduction in weaning weight reduced the profit of the Specialist-MTS flock by as much as $104,000 (8 per cent). However, profit reduced by <1 per cent for flocks that retained wethers older than 17 months of age.

Changing the stocking rate by 10 per cent from the optimum reduced the profit by as little as 2 per cent for the first 10 per cent change, but up to 10 per cent as the stocking rate moved further from the optimum. This pattern and

Table 9 The profit and production associated with the optimal farm plan for each flock structure, under baseline price conditions

	Profit ($ 000)	Ewe percentage (Ewe DSE/total DSE as a percentage)	Stocking rate (DSE/ha)	Supplement feeding (t)	Supplementary feed per DSE (kg/DSE)
Store	867	80	10.4	957	35
Shipper	853	67	10.1	857	32
MPL 10 mo	1,070	86	10.0	1,822	69
SRF-MTS	1,153	88	12.0	2,193	70
Specialist-MTS	1,266	100	13.7	2,831	79
Composite	854	76	12.8	1,210	36
Trade wether (17 mo)	636	0	8.5	207	9

Note: DSE, dry sheep equivalent; mo, month old.

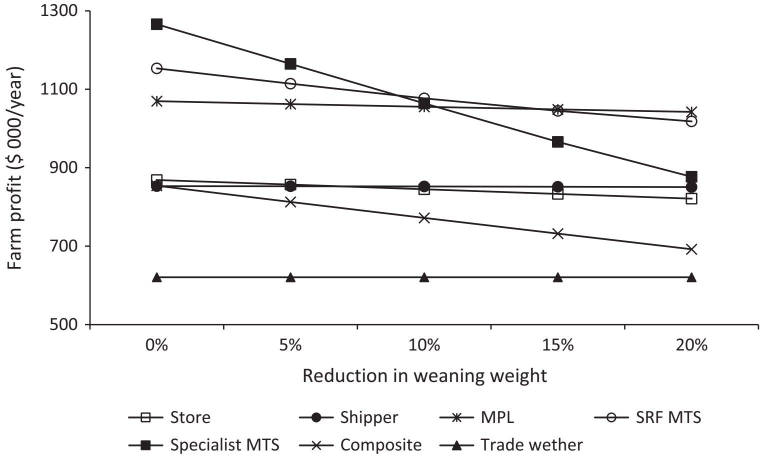

Figure 2 Whole-farm profit for each flock when lamb weaning weights were reduced.

the magnitudes of reductions in profit were very similar for each flock structure (Figure 3).

3.2 Crop and livestock integration

The optimal cropping proportion for the farm was between 40 per cent and 60 per cent, depending on the particular flock structure selected. Cropping proportions as low as 20 per cent and as high as 80 per cent remained economically viable (Figure 4). When testing the responsiveness of farm profit to alteration in cropping intensity, the total labour and machinery available were fixed at the baseline conditions, which likely made high and low crop percentages appear worse than they would be in practice if a

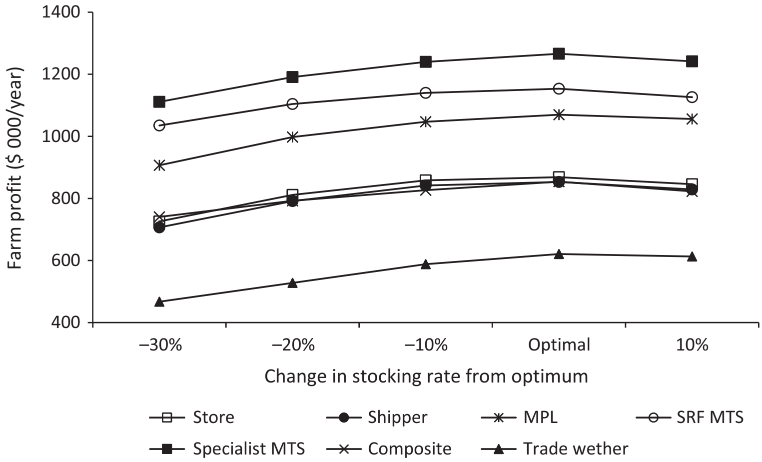

Figure 3 Farm profit when stocking rate of each flock was altered from the optimum.

strategic adjustment in the investment in cropping machinery and labour was undertaken. The ranking of flock structures was the same at all cropping levels, with Merino flocks selling finished lambs being the most profitable. A key finding was that, within 30–70 per cent cropping, farm profit was affected more by selecting the optimal flock than altering crop allocation (Figure 4).

Interestingly, rotation choice was independent of flock structure, with the optimal rotation on each land management unit being the same for all flock structures. Depending on the soil type, either a continuous crop or mix of continuous pasture and continuous crop rotations was selected (Table 10). On the poorest soil (S1), it was most profitable to have only continuous pasture. However, as the soil type improved, it became optimal to increase the proportion of continuous cropping.

Continuous cropping on the poor soil reduced farm profit by $80/ha, and a pasture crop rotation also reduced farm profit by $69/ha. Conversely, continuous pasture on the best soil reduced farm profits by $170/ha, and on the same soil, a pasture crop rotation reduced farm profit by $66/ha.

3.3 Price sensitivity

Increasing the carcass weight price of lamb, as expected, increased the profit of flocks turning off finished lambs, whilst decreasing the carcass weight price of lamb had the opposite effect. In contrast, increasing the wool price increased the profit of the flocks retaining wethers, whilst decreasing the wool price had the opposite impact. However, a 20 per cent increase or decrease in the carcass weight price of lamb or wool prices was not enough to alter the optimal flock structure (Figures 5 and 6). The relative profitability of the composite flock was the most sensitive to changes in the carcass weight price of lamb and wool prices, becoming more profitable at high prices for sheep

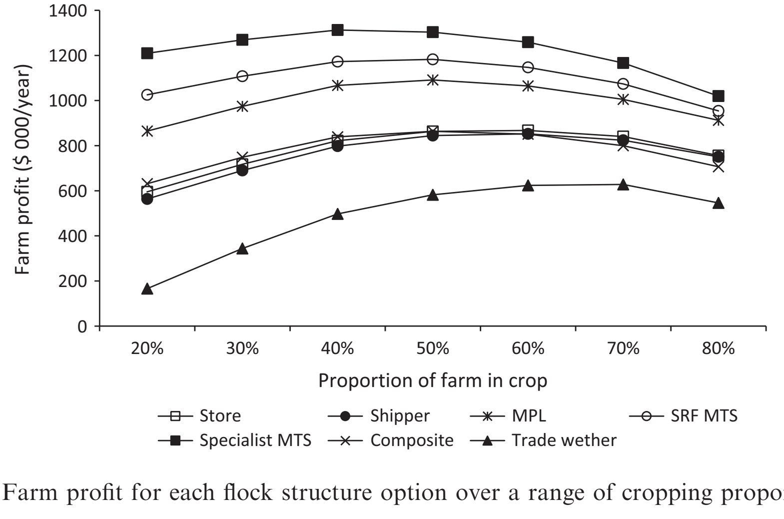

Figure 4 Farm profit for each flock structure option over a range of cropping proportions.

Table 10 LMU[†] optimal rotations and the number of hectares selected for each flock structure at the baseline optimal cropping percentage

Rotation[‡]	Area (ha)
S1-AAAA	1,120
S2-AAAA	496
S2-TBTOTH	1,072
S3-AAAA	989
S3-TBTOTH	2,156
S4-AAAA	25
S4-TBTOTH	522

Note: [†]Land management unit (LMU) S1 was the lowest quality soil, and S4 was the highest. The continuous pasture (AAAA) on S3 & S4 was constrained to a minimum level (989 ha and 25 ha, respectively) because some of these paddocks were unable to be cropped for various reasons such as landscape slope or rockiness. [‡]Only the selected rotations are included. For a list of all the possible rotations available in MIDAS, refer to Appendix S1. A, annual pasture; B, barley; O, oats; T, triazine-tolerant canola; W, wheat.

and low prices for wool. With high prices for lambs, the absolute profit of the composite flock increased the most, whilst with low prices for wool, the absolute profits reduced the least.

Figures 5 and 6 present the changes in profit from altered carcass weight prices of lamb sheep and wool relative or proportional to the profit of the shipping flock that sells wethers at 17 months of age. These relative profits were calculated to remove the impact of price changes on absolute profit levels, and to therefore highlight the differential impact of price changes between flocks.

Grains were a key input for the sheep enterprise, in the form of supplementary feed, and were also the key output of the cropping enterprise.

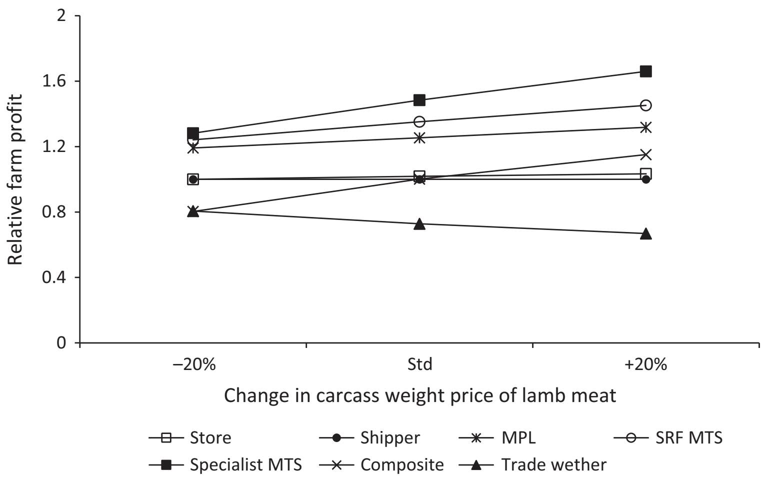

Figure 5 Farm profit for each flock structure relative to the shipper flock selling at 17 months (i.e. whole-farm profit of a given flock divided by whole-farm profit of the shipper flock), when the sheep price was altered (−20 per cent, unchanged, +20 per cent).

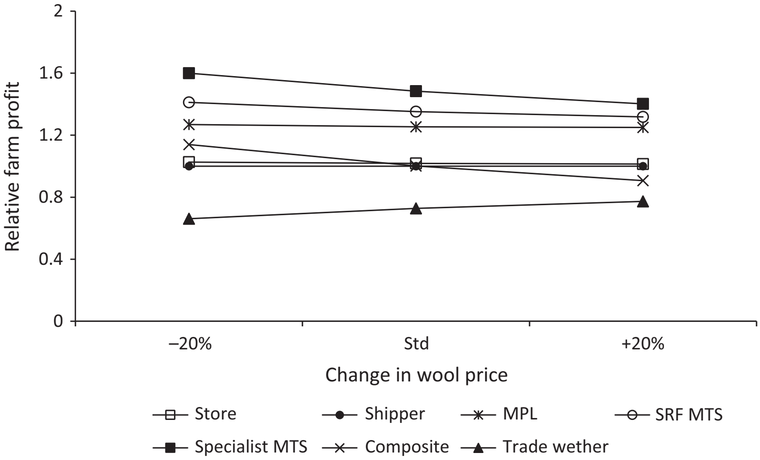

Figure 6 Farm profit for each flock structure relative to the shipper flock selling at 17 months (i.e. whole-farm profit of a given flock divided by whole-farm profit of the shipper flock), when the wool price was altered (−20 per cent, unchanged, + 20 per cent).

A 20 per cent increase in grain prices shifted the optimal cropping proportion towards 70 per cent and increased farm profit by up to 18 per cent (Figure 7). At crop levels below 20 per cent, however, the increase in profit was minimal because the cost of supplementary feed increased, reducing the profit of the sheep enterprise, and the volume of grain sold at the higher prices was small. In addition, the increase in supplementary feed costs was not enough to change the optimal flock structure. Merino flocks turning off finished lambs were still the most profitable (Figure 7).

A 20 per cent decrease in grain prices reduced farm profit compared to the standard case at cropping levels above 20 per cent. However, at crop levels below 20 per cent, flocks consuming large amounts of supplementary feed increased their profitability. Additionally, the optimal cropping proportion shifted to around 20–30 per cent and flocks turning off finished lambs became more profitable because of the access to cheaper supplementary feed.

A specialist first-cross flock mating all the ewes to terminal sires requires ewes to be bought in to replace the old ewes that are culled. This flock's profitability hence depends on the ewe price. In the baseline, it was most profitable to buy in 5-year-old replacement ewes. However, if the ewe price was >$108/hd (approximately 35 per cent more than current baseline price), it was more profitable to run a self-replacing flock (Figure 8).

The trade wether flock was significantly less profitable under the baseline price scenarios (Figure 1). However, the profit of the trade wether flock was highly dependent on the purchase price of store lambs. The price of store lambs had more effect on the profitability of the trade wether flock than the store flock because store lambs comprised a higher proportion of the flock. The breakeven store lamb price, when both the store lamb flock and the trade wether flock had the same profit, was $62.5/hd (Figure 9). If the price of store

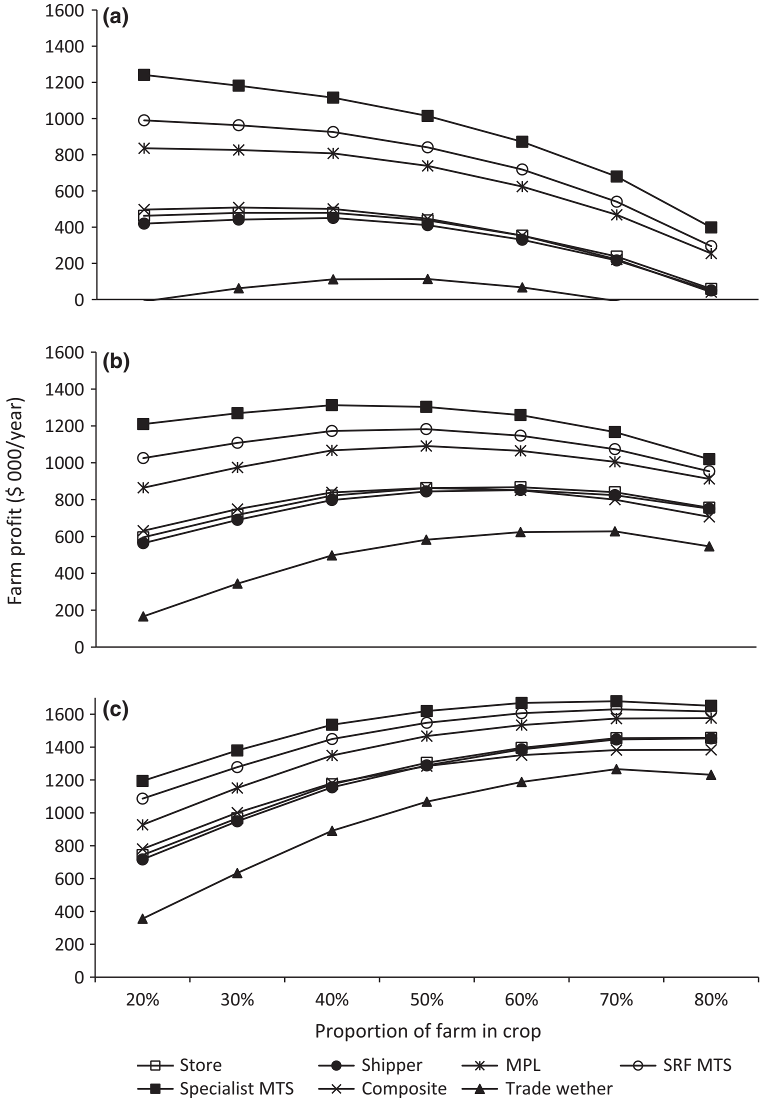

Figure 7 Farm profit for each flock structure at a range of cropping proportions when grain prices were (a) 20 per cent less, (b) unchanged, (c) 20 per cent more.

lambs dropped below this level, ceteris paribus, the trade wether flock had the potential to be a more appealing flock choice.

Altering the price of labour affected whole-farm profit (Figure 10). Reducing the labour price by 20 per cent increased farm profit by $170,000 per year, and the same percentage increase in the labour price had the opposite impact. Changing the labour price affected each flock structure similarly and therefore had no impact on a farmer's choice of flock structure.

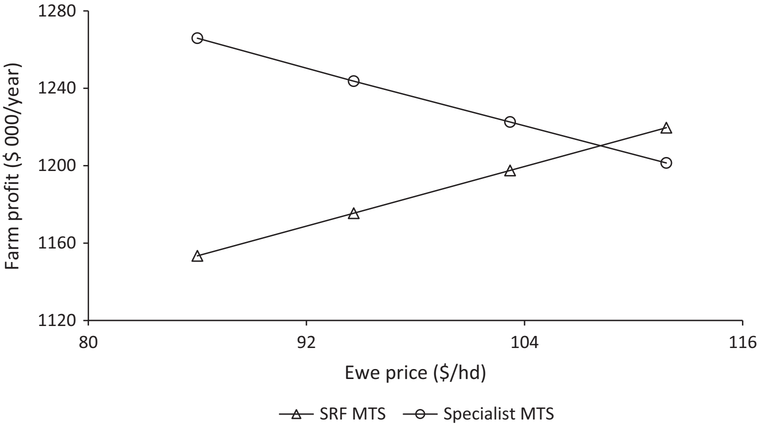

Figure 8 Whole-farm profit for the SRF-MTS and Specialist-MTS flocks, as ewe price altered.

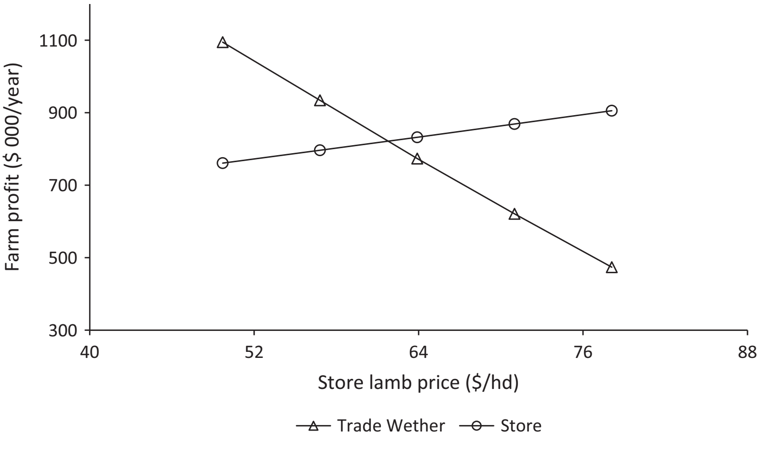

Figure 9 Whole-farm profit for the trade wether flock and store flock, as the store lamb price altered.

4. Discussion

4.1 Flock structure choice

Whole-farm profitability varied by $630,000 per year (or $99 per ha) between the least and most profitable flock structures evaluated (Figure 1). The most profitable flock structure generated almost double the farm profit of the least profitable flock structure ($1,266K vs $636K; see Table 9). This finding provides evidence to support the hypothesis that whole-farm profit in mixed enterprise farms in Australia currently is highly sensitive to flock structure. The most profitable structure was the Specialist-MTS flock turning off first-cross finished lambs, and the least profitable was the trade wether flock buying store Merino lambs and turning off export wethers. An earlier study

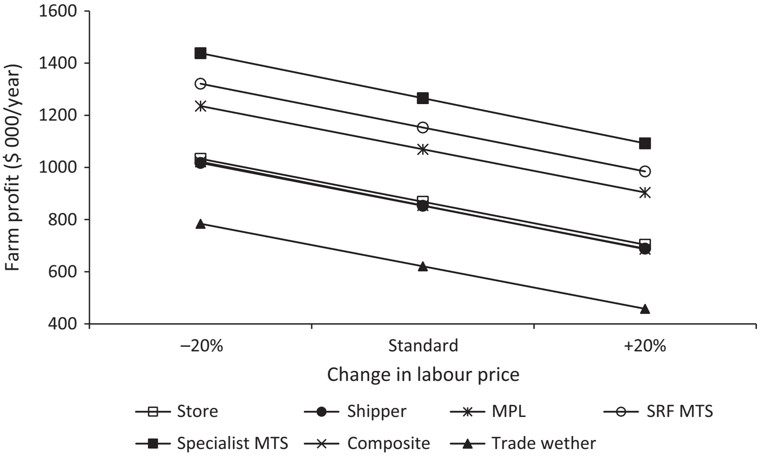

Figure 10 Whole-farm profit for each flock when labour price was altered (−20 per cent, unchanged, + 20 per cent).

of Kopke *et al.* (2008) found only a 19 per cent difference between the most and least profitable flock structures they examined. Their study used baseline prices for wool of 900 c/kg, whereas in the current study, the equivalent baseline price was 1,500 c/kg. The Kopke *et al.* study was undertaken in a period when sheep production was less profitable than crop production, and sheep production then was far less profitable than current sheep production.

Flocks selling finished wether lambs were more profitable than flocks selling store lambs or export wether hoggets. This is because these flocks produced large amounts of high-quality wool, valuable at current wool prices, from the Merino ewes whilst also turning off large quantities of high-quality finished lamb. However, to achieve these high profits required very sound sheep management, as indicated by the higher stocking rates (Table 9) and greater sensitivity to weaning weights (Figure 2.). To run higher stocking rates and maintain sufficient weaning weights requires appropriate ewe management and feed allocation. These flocks require superior management compared to the flocks retaining wethers (deBaca *et al.* 1956; Everett-Hincks *et al.* 2005). Nonetheless, if they are managed well, flocks running Merino ewes turning off finished Merino or first-cross lambs are significantly more profitable.

The stocking rates indicated to be feasible and optimal in this study are higher than commonly observed on farms. For example, in the study region, in the production year of 2018 when close to average annual rainfall was received, the average stocking rate was 7.4 DSE/ha and the top 25 per cent of farms, ranked by operating surplus/ha/mm of growing season rainfall, recorded an average stocking rate of 8.5 DSE/ha (Planfarm 2019). One reason for the difference in stocking rates is due to farmers being more risk averse (Bardsley and Harris 1987) than is assumed by the risk-neutral, profit-maximising framework of the modelling employed in this study. Another reason for the difference is that farmers do not have perfect knowledge about seasonal conditions and the quality and quantity of resources available to them to support animal production. In practice, farmers are less efficient in their resource use than occurs in a modelling paradigm underpinned by perfect knowledge and profit-maximising behaviour.

This study's results indicated that altering the stocking rate away from the optimum reduced farm profit (Figure 3). However, most importantly, the relative profitability between the different flock structures was not altered. Hence, if farmers selected to be, for example, 20 per cent below the optimum identified in this study, there was no change in the optimal flock structure. These results provide farmers, at least those in the region investigated, with confidence regarding the optimal flock structure, even if these farmers are risk averse or reliant on imperfect information that leads to a reduction in their farm's stocking rate.

The findings in this study are consistent with the general trend observed in Western Australia and many other sheep-producing regions of Australia, where the number of retained wethers relative to ewes is decreasing. Currently, wethers only make up 11 per cent of the national sheep flock (ABARES 2018b). Additionally, the proportion of ewes joined to terminal sires is increasing (Perrett 2015). This study provides confirmation that many farmers and the Australian sheep industry, in general, are making economically rational adjustments, as flocks selling first-cross finished lambs are the most profitable, closely followed by flocks selling finished Merino lambs.

It should be noted that this analysis has not included some factors that may either alter the profitability of the flocks assessed or alter the ability of a farmer to capture additional profit. These factors include the following:

1. the genetic value of the replacement ewes. When buying in replacement ewes, it can be difficult to determine the genetic value of the animals. In this analysis, it was assumed that the genetic value was the same as the 'home-bred' animals, but the responsibility for the genetic gain made in those ewes is passed to another manager and therefore may be different. For example, reproduction rate is affected by genetics (some sheep strains are more fertile) and also nutrition, whereby ewes given adequate nutrition prior to and during mating produce more and heavier lambs. Seasonal conditions that affect feed availability are known to affect lambing percentages (Young *et al.* 2011);
2. adjustment costs required to switch flock structures; and
3. variation in seasonal conditions between years. Ewe and lamb production is more sensitive to nutritional variation than wethers producing wool. Flocks with 100 per cent ewes turning off lambs are also inherently less flexible than flocks with a high proportion of wethers. They are less flexible because for parts of the reproductive cycle, ewes cannot be moved

and are therefore unavailable for sale at those times and farmers are usually less willing to sell ewes if seasonal conditions are poor. Therefore, the potential for increased costs is higher for ewe dominant flocks in poor years. It is assumed that the difference in profitability in average and better years offsets the extra costs in a poor year. This assumption deserves further analysis but is outside the scope of this analysis.

4.2 Crop management

For farmers with a primary business motivation to maximise profit, the modelling results indicate the prime importance of the choice of flock structure over the choice of cropping intensity. Flock structure had a larger impact on profit than moderate changes in land use (Figure 4). However, if farmers were satisfied with their flock structure, profit could be increased by shifting their crop allocation between 40 per cent and 60 per cent of the farm's arable area. This is lower than the current average in the south-west region of Western Australia where, on average, 64 per cent of agricultural land is devoted to cropping (ABARES 2017). Reducing the proportion of crop from 60 per cent to 50 per cent, for the baseline modelled farm, increased farm profits by up to $45,000. Additionally, selecting the correct rotation for each soil type was important. It was most profitable to have continuous pasture on the less productive soils and continuous crop, with complementary smaller areas of continuous pasture, on the more productive soils. Selecting the wrong rotation reduced profits by up to $170/ha.

The greater relative profitability of the sheep enterprise compared to cropping was revealed in the optimal farm plans across all flock options being based on 40–60 per cent of the farm area being for cropping. By contrast, Kopke *et al*. (2008) found a higher range of optimal land allocation for cropping, 53–65 per cent, in their examination of flock structures. Their results are attributable to the sheep enterprise, in that period, being relatively less profitable than cropping.

Although there are many interactions between cropping and livestock operations, rotation selection and crop allocation did not affect the choice of flock structure and vice versa. This means farmers can independently alter their flock structure and crop management, which provides confidence in the flexibility of the mixed farm system.

4.3 Price variation

Flocks that produced a balanced mix of wool and sheep for sale were less exposed to separate changes in wool or sheep meat prices. Price variation had the greatest impact on the profitability of flocks based on either a composite genotype (meat emphasis) or a Merino flock dominated by wethers (wool emphasis). However, the choice of the optimal flock structure was robust to price changes as large as 20 per cent. Yet, prices are predicted to remain within 20 per cent of the baseline prices assumed in this study, at least for the next few years according to ABARES (2019). Furthermore, Australian sheep meat production operates in a global red meat market and Australia as a supplier of sheep meat is a small player in the international red meat market that is dominated by beef sales (Berry 2017; Meat and Livestock Australia 2018). Changes in the Australian supply of sheep meat will be constrained by the historically small size of the Australian sheep flock (Meat and Livestock Australia 2019) and the impact of recent drought. Hence, any incremental increases in sheep meat production associated with changing flock structure are unlikely to alter sheep meat prices by a magnitude sufficient to alter the optimum flock structure.

Flock structure also was robust to price changes in key inputs such as supplementary feed and labour. However, the profitability of flocks purchasing sheep, such as the Specialist-MTS and trade wether flocks, was affected differently if specific classes of sheep sufficiently changed in price. For example, an increase in the price of ewes reduced the profitability of the Specialist-MTS flock. However, ewe prices needed to increase by over 35 per cent before switching to a self-replacing flock became more profitable. Similarly, the price of store lambs had to drop by over 35 per cent before farmers would consider a trade wether flock, which is unlikely given that the price of store lambs is driven by the demand for lambs to feedlot; therefore, the lack of demand from store wether buyers is unlikely to drive down the price.

Selection of a Merino flock that turned off finished lambs also helped mitigate risks associated with variation in grain prices. This flock structure depended on supplementary feed, so if grain prices dropped, then the loss of crop income could be offset by cheaper sheep feed. In general, farmers can be confident with their choice of flock structure in the face of market uncertainty.

4.4 Caveats

Some important caveats apply to this study's findings. Care was taken to ensure the farm model presented here accurately captured the characteristics of a particular farm in the grainbelt of Western Australia. Accordingly, the modelling results will aptly apply to that farm business. However, generalising the study findings to other farms becomes increasingly problematic: the more the distant those farms are from the modelled farm, the more different the characteristics of those other farms are, regarding soil differences, farm size, enterprise mix, machinery complement, labour force and managerial goals. Nonetheless, the magnitude of the additional profit identified as potentially available from selection of the optimal flock structure does suggest that the key finding regarding the economic importance of sheep flock selection is likely to be widely applicable.

The steady-state deterministic modelling framework used in this study, of necessity, overlooks the economic consequences of climate variability, weather year sequences and costs of interyear adjustments. In practice, farmers alter their farm's flock structure over a handful of years and the nature of weather years and commodity prices during those years can greatly affect farm financial outcomes. These considerations, however, are outside the scope of this study. Nonetheless, the identified superior profitability of some flock structures identified in this current study indicates that, even in the face of some sizeable adjustment costs, adoption of those superior flock structures is warranted, if farm profitability is to be enhanced.

Another important caveat is that the analysis takes no account of the negative environmental externality associated with sheep production, namely greenhouse gas emissions (Browne *et al.* 2011; Cottle *et al.* 2016). Until regulation or market-based mechanisms are introduced to internalise this externality, then profit-maximising farm businesses have little incentive to consider the greenhouse gas emissions associated with sheep production. Yet, these emissions are known to be a main source of agricultural emissions (Thamo *et al.* 2013).

5. Conclusion

Whole-farm planning allows farmers to identify what areas of the farm system are current and potential drivers of profit, and how they should be managed to maximise whole-farm profit. We have conducted a whole-farm analysis that illustrates how the structure of a farm's sheep flock, its rotations across a range of soils and overall cropping intensity are all factors that significantly affect profit and need to be considered when determining an optimal farm strategy.

This study assessed the role and profitability of different flock structures in a mixed enterprise farm business in the grainbelt region of Western Australia. We found that farm profit was greater when a Merino flock turning off finished lambs was selected. These flocks remained the most profitable among a range of flock options, even if key input prices and commodity prices were subject to moderate change. However, to achieve the maximum profit, these flocks required more attention to sheep management.

Choice of flock structure had a larger impact on profit than moderate changes in land allocation to cropping. Selection of the most profitable flock structure generated double the farm profit from that of the least profitable flock structure. More conservatively, a farm plan based on cropping and a self-replacing Merino flock using surplus ewes for first-cross, meat lamb production earned 33 per cent more profit than a farm plan based on a traditional self-replacing Merino flock that emphasised wool production.

An additional feature of optimal farm plans was to commit to continuous pasture on all the poor soils whilst continuously cropping the more productive soils, with some complementary areas of permanent pasture.

Allocating 40–60 per cent of the farm area to cropping was optimal, although this was affected by relative commodity prices.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Calibrating MIDAS to a large farm on the western edge of the Western Australian Grainbelt.