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An Agro-economic Model that Optimises Crop-Pasture-Fallow Rotations from all Theoretical Possibilities

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Abstract

Due to the existence of interactions between crops, pasture and livestock, crop-pasture rotations are more complex systems to model compared to continuous cropping rotations. The inclusion of a “long fallow” phase that interacts with both crops and livestock further increases this complexity. This paper explains a linear programming model developed by the Victorian Department of Natural Resources and Environment. The model represents the mixed grain/sheep farming system of the Victorian Mallee region where crops are rotated with annual legume pasture and “long fallow”. Model runs have highlighted important issues in relation to the objective of profit maximisation and the trade-off against risk management by farmers.

Introduction

The Economics Branch of the Victorian Department of Natural Resources and Environment (NRE) has been using Linear Programming (LP) models to estimate water demands and water use efficiency levels in irrigation areas (Eigenraam and Stoneham, 1997; Eigenraam et al, 1996), and the evaluation of research and development (R&D) projects by estimating on-farm benefits (see Jones and Soligo, 1996). Estimation of benefits in these benefit-cost analyses (BCA's) was further improved by measuring productivity changes using LP models (Stoneham et al, 2000).

Based on the same approach as in the MIDAS (Model of an Integrated Dryland Agricultural System) wholefarm LP models developed by the Western Australian Department of Agriculture in 1980's, PRISM (Profitable Resource Integration, Southern MIDAS) models have been developed for Victoria and New South Wales. In the past, these models were built for other purposes such as provision of decision support for farm advisers (Faour *et al*, 1999, O'Brien, 1999; Wimalasuriya, 1999). Later in 1999, the Victorian Department of Natural Resources and Environment (NRE) started using the PRISM models, to estimate productivity changes in R&D evaluation.

The ability of LP models to account for substitution between different enterprises and to present input-output tables made them amenable to estimating productivity changes due to changes in technology. However, both MIDAS and PRISM models had some inherent limitations when it came to using the models for estimating productivity changes. These limitations relate to the approach adopted when building the models to optimise crop rotations. The limitations that are explained below in the following section result from having only a pre-determined set of common cropping or crop-pasture rotations as activities in the LP matrix.

NRE commenced researching with the aim of developing a new approach where the model develops the optimal cropping rotation given all possible choices of crop sequences. The Economics Branch of NRE in 1999, was successful in discovering an innovative approach to model wholefarm systems. This is an unrestricted approach in contrast to restricting the solution within a pre-determined set of cropping rotations. EMAR-Wimmera (**E**conomic **M**odel of **A**gronomic **R**otations) was the first to be modelled using this new approach.

However, this was a continuous cropping model. The real challenge for NRE was to develop a mixed grain-sheep farming system model using this new approach. EMAR-Mallee wholefarm LP model, which is explained in this paper, is the result of taking this challenge up. The objective of this paper is to explain why an innovative approach of wholefarm LP modelling was needed, and to present details of the farming system, the model and preliminary results.

Wholefarm Modelling

The MIDAS and PRISM models mentioned above solve for the optimal crop (or crop-pasture) rotation out of a pre-determined set of rotations. Rotation effects on crop yields are considered in determining the rotation gross margins. When applying this method it is possible to have rotations with different lengths in the same model. Some examples for activities of the LP matrix in such models are Canola-Wheat-Barley; Lentils-Canola-Wheat; Lentils-Canola-Wheat-Barley; and Canola-Wheat-Barley-Lentils-Wheat.

There are two major limitations in using this method to model a farm system. Firstly, the solution is confined within the restricted set of pre-determined rotations. This results in the model being unable to be used to evaluate new crop varieties and any potential rotations. Secondly, it is necessary to build a completely new model for any other agro-climatic region because the crop and rotation choices will be different.

The new unrestricted approach for modelling wholefarm systems was developed by the Economics Branch of NRE to overcome the above limitations. The LP solves for the optimal cropping or crop-pasture rotation, from all possible crops, pasture and fallow after all possible two-year paddock histories. Activities in the LP matrix in this method are single crops, pasture or fallow after each possible two-year history. Some examples are Wheat after Wheat-Wheat; Wheat after Wheat-Lentils; Canola after Pasture-Fallow; and Pasture after Wheat-Canola.

This is an unrestricted approach where new crop varieties and potential rotations can be evaluated. The newly developed EMAR-Mallee Model was built using this innovative approach. The EMAR-Mallee model was built to analyse the wholefarm implications of technology changes at a regional level. Therefore, the level of detail in the model has been confined to what is really needed to fulfil the purpose. The wholefarm model is based on a representative farming system of the Mallee region of Victoria.

The Farming System Modelled

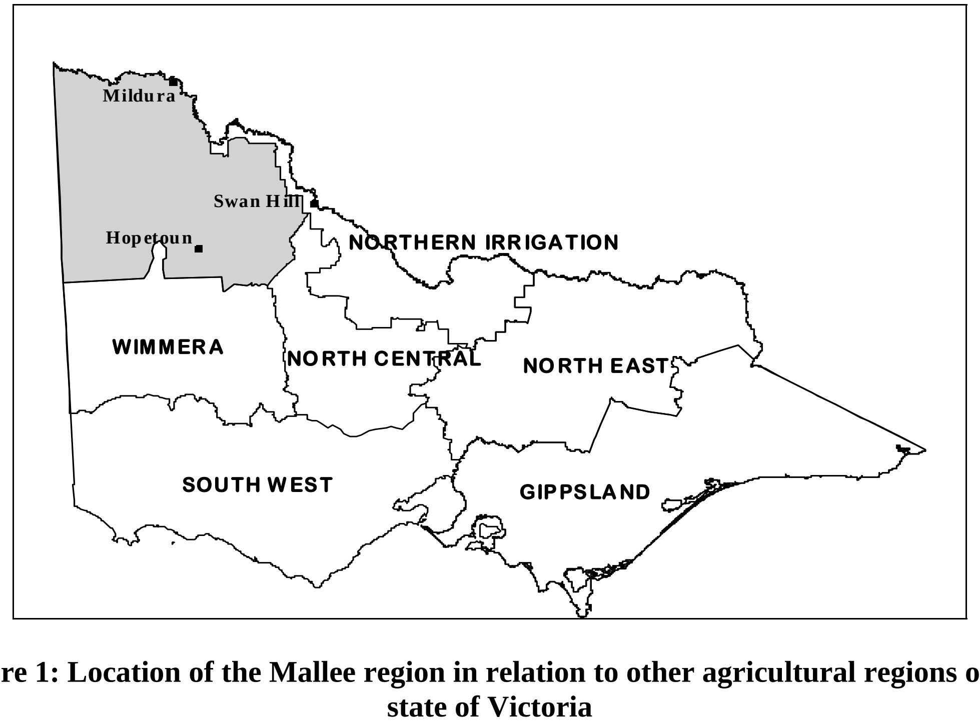

Figure 1: Location of the Mallee region in relation to other agricultural regions of the state of Victoria

The EMAR-Mallee model represents the pasture-crop rotation system on calcareous sandy loam soils of the Mallee region in Northwest Victoria (see the shaded area in Figure 1). The Victorian Mallee region is approximately 4.3 million ha with 2.6 million ha occupied for agricultural purposes. It is contiguous with the Mallee areas of South Australia and New South Wales. The Victorian Mallee region is semi-arid to arid with annual rainfalls ranging from 250 mm to 375 mm. The growing season is between May and October with approximately 60% of total annual rain falling in this period.

Broadacre cropping is the most important land use in the dryland Mallee with cereal crops, pasture and fallow accounting for most agricultural land in the region. On average, only half of the arable area is cropped in any given year and the rest is under annual medic pasture or fallow. The average farm size is 2,800 ha. Sheep are the most important livestock farmed in the Victorian Mallee with a population of 1.5 million. Only 25% of these ewes are mated to Merino rams and the most common sheep enterprise is a terminal sire over Merino ewe to produce first cross prime lambs.

Traditionally, the dominant crop rotation in the region was either one or two cereal crops followed by either one or two years of pasture including a fallow phase. The pasture and fallow phase has been used primarily as a break for cereal root diseases while fallowing was believed to conserve moisture for the following cereal crop. However, this moisture benefit of fallowing except in extremely dry years is now under debate and the weed control benefits of fallowing are becoming increasingly important. The fallow phase of the rotation is explained in section Modelling of Crop, Pasture and Fallow Phases in Appendix 1.

Matrix Development

Being developed in the 1940's for military operations, Linear Programming (LP) is widely used in business and commercial planning today (Dent, *et al*, 1986). It is a mathematical programming technique and mathematical programming is one class of operations research.

The technique can be applied to a wide range of problems with the following characteristics: a range of activities are available to choose from, constraints prevent free selection from the range of activities, and a quantifiable objective needs to be specified for optimisation. These activities in columns and the constraints in rows form the LP matrix.

The LP matrix of EMAR-Mallee consists of two sub-matrices that are optimised simultaneously. One of these is the cropping sub-matrix that contains crops, pasture and fallow. The other is the sheep sub-matrix for optimising the stocking rate and the feeding options depending on the pasture and stubble provided by the cropping sub-matrix (see Figure 2 below).

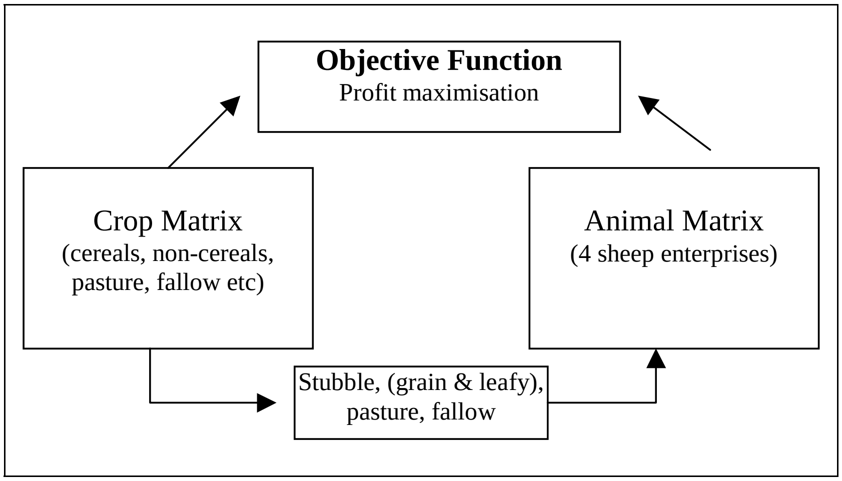

Figure 2: Linkage between the crop and animal sub-matrices

The cropping sub-matrix

Crops considered are Wheat (Wh), Barley (Bl), Field Peas (Fp), Lentils (Lt) and Canola (Ca). Once a model is developed with one or two crops in each category, these can easily be replaced with any other crop belonging to the same category. The technical details of modelling crop and stubble yields, pasture and fallow are explained in Appendix 1.

An LP matrix would generally consist of "activities" in columns and resource "constraints" in rows. Matrix "coefficients" that contain the quantity of a resource that is used or supplied by a unit of an activity, link these two. Activities in the cropping sub-matrix are each of the 6 crop, pasture and fallow option after every theoretically possible two-year paddock history (Figure 3). The constraints are for transferring paddock histories as explained below.

Paddock History		*WhWh*					
Current crop Year 1		**Wh**	**Bl**	**Fp**	**Ca**	**F**	**P**
Budget	$	-88.15	56.28	88.09	126.04	-43.29	-26.00
Area	ha	1	1	1	1	1	1
Histories from Y1 to Y2:							
WhWh		-1					
WhBl			-1				
WhFp				-1			
WhCa					-1		
WhF						-1	
WhP							-1

Figure 3: Cropping sub-matrix to show the activities and transfer rows

Following is a summary of activities of the cropping sub-matrix:

No. of crop/pasture options	6
No. of 2-year histories	36
No. of options (each year)	216 (6 x 3, each crop after each history)
Maximum length of rotation	6 years
Total No. of Activities	1,296 (216 x 6)

"Transfer Rows" are used to transfer the 2nd crop of the history and the crop selected in the current year as the two-year history for the following year. For example, if the selected option in the 1st year is wheat after pasture-fallow, a history of fallow-wheat will be transferred to the 2nd year. These history transfers will occur from Years 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 6 and 6 back to 1. Therefore, the model will develop a rotation by choosing a single option for each year, so that the 6 selected options would form a continuous rotation that maximises the gross margin of the total rotation. Activity budgets for crops contain the gross margin of each crop after each history while those for pasture and fallow contain a summary of the variable costs.

An example for a 6-year rotation chosen by the model would be as follows. The crop chosen for each year is in bold while the corresponding paddock history is in Italics.

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
*Ca-Wh-***Fp**	*Wh-Fp-***Ca**	*Fp-Ca-***Wh**	*Ca-Wh-***Bl**	*Wh-Bl-***Ca**	*Bl-Ca-***Wh**

The objective function to be maximised by this LP model is the total rotation gross margin plus sheep gross margin. The rotation gross margin depends on the gross margins of all crops of the rotation chosen. Gross margin of a crop depends on its yield, price and input cost. Yield and the rate of nitrogen fertiliser applied for the same crop may differ depending on the paddock history. Unless these differences are considered in calculating the gross margins, an LP model would choose only the most profitable crop for all the years of the rotation.

It is possible to choose between 3, 4, 5 and 6 years as the length of the rotation. This is important because the optimal length of a cropping or crop-pasture rotation can change over time with new crops being adopted and existing enterprises being less profitable. For example, the optimal length of a rotation in the Mallee has traditionally been 3 years, pasture-fallow-cereal, but is now changing to 4 years with 2 cereals instead of 1. The main reason is the change in the relative profitability between cereals and sheep. Further, new crops and crop varieties with different levels of disease-resistance etc become available so it is possible to test for their rotation effects.

The sheep sub-matrix

This part of the matrix contains the feed budgeting for 4 sheep enterprises on a monthly basis to fulfil the monthly demand of the flock for metabolisable energy (ME) within the dry matter (DM) intake capacity. The sheep sub-matrix receives herbage from medic pasture and fallow as well as stubble, from the cropping sub-matrix. Herbage from pasture and fallow (up to working of the killed pasture) could either be fed during the month as green feed or be carried-over to the following month with quantity and quality penalties, to be fed as dry feed. Stubble has got two fractions and the grain fraction can only be eaten within the first month after the crop is harvested. The leafy fraction of stubble is available for grazing for 4 months after harvesting. Any feed gaps can be supplemented with purchased feed grain.

EMAR-Mallee Productivity Estimates

NRE's economic evaluation system is applied to assist resource allocation between R&D projects which comprise of a qualitative and a quantitative component (Stoneham et al, 2000). The objective of resource allocation decisions is to maximise wealth, or well being, in the Victorian economy. The quantitative component attempts to measure the gross benefits derived from a research-induced technical change.

NRE's quantitative economic evaluation system

Economic surplus is the standard measure of benefit[1]. A research-induced technical change is a shift of the supply curve downward (see Figure 4)[2]. Every producer is able to produce each unit of output at lower cost, due to the new technology.

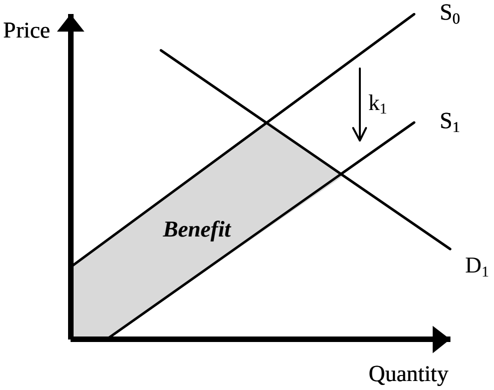

Figure 4: Downward shift of the commodity supply curve due to technical change

Following Alston et al. (1995), the cost reduction from a technological change is denoted by the letter k. The k associated with the first round of a technology impact, that is, before any alterations to the farming enterprise take place, is denoted k_1. It is the impact that occurs when a technology is adopted, but the use of (other) inputs remains constant. Since the purpose behind research is to prompt a change in on-farm practices, a more satisfactory description of the technology's impact is one that takes account of the altered producer behaviour. This is measured by k_2, the cost reduction after input use has changed (see Figure 5).

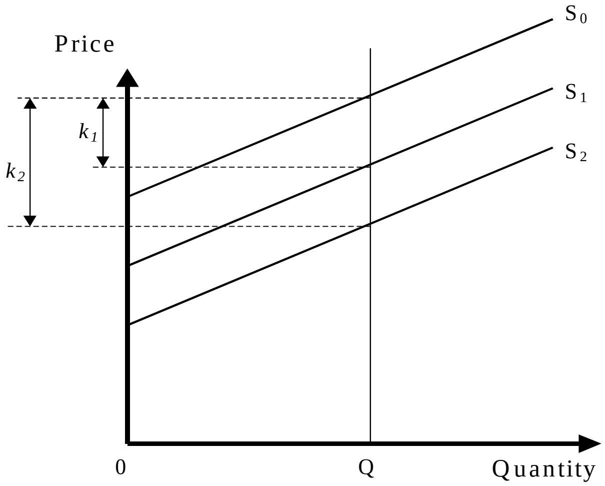

Figure 5: k_1 versus k_2

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[1] For a more complete exposition about Economic Surplus and related concepts see Alston *et al* (1995).

[2] For an explanation of demand and supply, see Tisdell (1972).

Measuring productivity changes

Practically, k_2 is found by measuring the change in productivity. Basically, a productivity change is the difference between the rate of output and input growth. The process of measuring productivity change using linear programming models involves running two different scenarios: the base-case, or the 'without' new technology scenario; and the 'with' new technology scenario. The 'with' scenario is determined by translating technology into an appropriate parameter adjustment in the cropping or sheep sub-matrix.

The magnitude of a research shock will depend on the significance of 'improved inputs' (or 'improved outputs'). An improved input (or output) is one that is directly affected by research. The greater the proportion the improved input (or output) is to total input expenditure (or total revenue), the larger the productivity improvement is likely to be (all things being equal).

Since productivity is the ratio between outputs over inputs, productivity gains could be achieved either by reducing inputs or by increasing outputs. Breeding of a new wheat variety that yields more than the existing ones using the same amount of inputs, for example, would enable farmers to produce more at the same cost as before. This means the cost of producing the same output would fall. An input-output summary table produced by EMAR-Mallee in measuring productivity change due to breeding a new wheat variety that yields 10% more than the current one, is presented in Table 1 below, as an example. The column "t-1" is the "without" scenario while column "t" is the "with" scenario.

Table 1: A sample input-output summary table

	t-1	t	% growth
inputs	100	100.1416	0.1416
outputs	100	105.1238	5.1238
PRODUCTIVITY (percent)			4.9822

At the same time, the area under wheat may increase at the expense of some other crop if this new variety is adopted. An optimising LP model can capture these substitution effects. Input reductions may include new crop varieties that are resistant to particular diseases prevailing in a region, so that the need for a routine spray is eliminated.

However, it is possible to improve productivity without changing the quantity of either inputs or outputs. This is by way of improving the quality of the output so that a higher price is attracted. This type of a productivity change is measured by considering the output with and without the quality improvement as two different farm outputs.

Input-output tables

The use of farm inputs and the production of outputs depend on the optimal cropping or crop-pasture-fallow rotation chosen by the respective model run. Therefore, the quantity and the price of each farm input and output for each of the crops, pasture, fallow and sheep are put into a table. This table is used to measure the change in total factor productivity due to technological change, using the "Fisher Index" (see Alston *et al*, 1995).

Model Results

EMAR-Mallee was first optimised letting the model to develop the optimal cropping or crop-pasture rotation out of all crop, pasture and fallow options after all possible paddock histories. The results of this optimisation are explained below as the “standard solution”.

The common practice among farmers in the Mallee, which is rotating cereal crops with pasture and fallow without growing non-cereals, was then analysed and the results are presented below. Finally, a sensitivity analysis was performed to determine the breakeven yields needed for field peas and canola to replace pasture and fallow as break crops in the rotations.

Standard solution

Standard model runs were performed using current market prices for crop inputs and five-year average prices for grains and livestock products. The model was optimised under different lengths of crop rotations and the results are shown in Table 2.

The optimal rotation under any length didn’t include pasture or fallow and hence sheep as well. The optimal six-year rotation was simply a repetition of the three-year rotation. The three-year rotation was the most profitable and yielded $7/ha higher gross margin than the four-year rotation. The four-year rotation had $5/ha higher gross margin than the five-year rotation.

Table 2: The optimal crop rotations of the standard runs

Length of crop rotation (yrs)	Optimal rotation	Average gross margin ($/ha)
3	Fp-Ca-Wh	180
4	Fp-Ca-Wh-Wh	173
5	Fp-Ca-Wh-Ca-Wh	168
6	Fp-Ca-Wh-Fp-Ca-Wh	180

However, the common practise among farmers in the Mallee region is to grow cereals with a pasture and a fallow phase. Growing non-cereal crops such as pulses and canola is considered by the majority of farmers in the region to be too risky given the uncertainty of receiving enough rainfall distributed throughout the growing season. On the other hand, sheep are considered important as an insurance against crop failure. Sheep are not directly or immediately affected by dry years and could be sold at least at a lower price to cover some losses incurred in cropping. Therefore, a scenario without growing non-cereal crops was analysed using EMAR-Mallee.

Scenario analysis

EMAR-Mallee model was optimised under different lengths of crop rotations with cereal crops, pasture, fallow and sheep (Table 3), non-cereal crops were excluded. The three-year rotation was the most profitable and yielded $15/ha higher gross margin than the four-year rotation. The four-year rotation had a similar gross margin to the five-year rotation.

Table 3: The optimal crop rotations when non-cereal crops are excluded

Length of crop rotation (yrs)	Optimal rotation	Average gross margin ($/ha)
3	F-Wh-Bl	153
4	P-F-Wh-Wh	138
5	F-Bl-F-Wh-Wh	138

The model chose sheep irrespective of whether the optimal rotation had pasture or not. This is because the fallow is also a volunteer medic pasture up to being worked in. Fallow can provide grazing for sheep even after being killed with herbicides. Fallow incurs 66% more cost than a pasture due to the high amount of herbicides and workings.

However, fallow becomes more profitable than pasture within the context of the whole rotation because of its carry-over benefits (moisture, weed control etc) on the next two following crops. On average, yield benefits on the following crop from fallow is 40% more than that of pasture, while the benefits on the second crop following fallow is 30% more than that following pasture.

Sensitivity analysis

The standard solution above shows that it is more profitable to use non-cereal crops as break crops between cereals compared to pasture or fallow running sheep. However, farmers in the Mallee region aren’t sure whether they’ll be able to get a reasonable yield from non-cereal crops and what that “reasonable” yield should be. The following sensitivity analysis was performed to determine the breakeven yields needed for field peas and canola to replace pasture and fallow in the rotations.

These two crops were analysed using five different yields for each of them resulting in 25 combinations (see Table 4). The length of the rotation considered in the analysis was 4 years. The range of yields started from 50% of the expected yields in an average rainfall year. The standard yields or field peas and canola were 1.27 and 1.22 t/ha, respectively. The results are shown in Appendix 2.

Table 4: The range of yields used in the sensitivity analysis

Yields considered for field peas		Yields considered for canola	
% of expected yield	t/ha	% of expected yield	t/ha
50%	0.63	50%	0.61
60%	0.76	60%	0.73
70%	0.89	70%	0.85
80%	1.01	80%	0.97
90%	1.14	90%	1.09

When the yield of both non-cereal crops were reduced to 60%, the model chose P-F-Wh-Wh. When canola yield was increased to 0.97 t/ha, canola replaces pasture in the rotation. The resulting rotation was F-Wh-Ca-Wh. Field pea comes into the optimal rotation only when its yield reached 1.01 t/ha at higher canola yields. This resulted in the rotation Fp-Ca-Wh-Wh.

When field pea yield is as high as 1.14 t/ha, the optimal rotation becomes F-Wh-Fp-Wh at lower canola yields.

It's evident from the above analysis that farmers need to obtain a yield of approximately, 1.00 t/ha for both field peas and canola in an average rainfall year in order to be able to grow non-cereals as break crops between cereals instead of pasture and fallow. However, the ability of a farmer to move from cereal rotations with pasture and fallow towards continuous cropping with non-cereal crops as break crops depends on the financial situation and the risk-attitude of the farmer.

A risk-averse farmer may prefer to receive a lower income in good years but at least something positive in a bad year. This is possible with the more traditional low-risk systems that currently exist. So, the movement from pasture/fallow to non-cereals as break crops could result in some major changes in the farming system, such as:

- increased variable costs that may cause negative gross margins in low-rainfall years,
- greater reliance on rainfall thus exposing to greater risk,
- not utilising the feed potential of crop stubble,
- increased farm income in good rainfall years, and
- reduced ground water recharge and soil erosion due to the absence of fallow.

Concluding Remarks

Although the LP matrix looks complicated and large with 1,389 activities and 692 constraints in both sub-matrices, it is fairly straightforward to model all theoretically possible rotation options using the approach presented in this paper. A major proportion of the constraints is simply to transfer the paddock histories between years so that the model will develop the optimal cropping or crop-pasture rotation.

This is an innovative, unrestricted approach to model wholefarm systems. Once the LP matrix and the data entry spreadsheet are developed with any six crops (or crop, pasture, fallow options), this type of a model can be used for any geographical region by simply replacing the crops, and their yields, prices and inputs.

The only major work necessary before the model can be used for a new agro-climatic region is the development of expected crop yields after each two-year paddock history. Group facilitation skills, a brief understanding of rotational effects on crop yields and a commitment to obtain active participation of local extension and research scientists are important in undertaking this task.

The ability of wholefarm LP models to account for substitution between different enterprises makes them a powerful tool for estimating productivity changes due to research-induced technical shocks. The conventional method of wholefarm modelling with a pre-determined, restricted set of cropping rotations confines the solution to be within this set in each regional version. The sensitivity analysis presented above has resulted in 4 different rotations within the 25 yield combinations of two crops. This was possible only because all the rotation options are available in the EMAR-Mallee model to choose from.

Acknowledgments

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Appendix 1: Technical Data of EMAR-Mallee

Modelling of Crop, Pasture and Fallow Phases

Crop production

The gross margin of a crop may vary due to the differences in its expected yield depending on the paddock history. Expected yield of wheat for example, should be higher after a pulse crop than after a cereal crop, due to the disease break and nitrogen fixation.

For each crop, a potential yield for an average rainfall year that could be obtained after the best paddock history for that crop was finalised during the group discussions. In order to link these yields to rainfall, potential "water use efficiencies" (French and Schultz, 1984) were estimated using the fixed evaporation losses as shown in van Rees and Ridge (1994). Crop yield data from research station trials as well as from top farmers in the region together with corresponding growing season rainfall (April to October) were considered in these estimations.

Potential water use efficiencies were estimated by dividing the potential yield in kg by water use. Water use is the growing season rainfall plus soil water minus evaporation losses.

Potential WUE (kg/ha/mm) = Potential yield (t/ha) x 1,000 (kg/t) / WU (mm)
Where;
WUE: Water Use Efficiency
WU: Water Use

WU = GSR + Soil water – Evaporation losses
Where;
GSR: Growing Season Rainfall (cumulative rainfall from April to October; van Rees and Ridge, 1994)

GSR for Northern part of Victoria is approximately, 65-70% of the annual rainfall. The percentage increases when the annual rainfall becomes higher than average.

Potential water use efficiency (WUE) and evaporation losses for each crop for the Mallee region are shown in Table 5. These figures are used in the model to arrive at potential crop yields for a given rainfall. The next step during the discussions with extension staff was to develop the expected differences in crop yields depending on the paddock history of the rotation. According to the experience of research and extension staff of the Mallee region, it was assumed that a paddock history of two previous years is long enough to capture a significant amount of this yield variation.

Table 5: Potential water use efficiencies (WUE) and evaporation losses in the Model.

Crop	**Potential WUE**	**Evaporation losses**
	(Kg/ha/mm)	(mm)
Wheat	21	110
Barley	21	90
Field Peas	11	130
Canola	9	110

Weed, disease and moisture status that could be expected as a result of each two-year paddock history were considered in developing percentages by which the potential yield of each crop would be reduced (or increased in the case of a crop immediately following fallow).

$$\textbf{Expected Yield} = \textbf{Potential Yield} - \textbf{\% Weed Effect} - \textbf{\% Disease Effect} \pm \textbf{\% Moisture Effect}$$

Crop inputs were considered to be of the standard recommended rates as in the regional gross margin book (Hall, 1998), except for nitrogen fertiliser. Based on the available soil test data from trials and farmers, the group of local extension and research staff has established an expected level of deep soil nitrogen (kg N/ha) after each two-year paddock history. Then, the requirement of soil nitrogen to produce the expected yield of a crop after each paddock history was estimated. Any deficit in soil nitrogen was considered to be applied as fertiliser nitrogen, costed and put into the activity budgets.

Stubble production

Stubble yields for cereals and pulses are calculated, depending on the grain yields. The two edible fractions of stubble available for grazing are calculated in terms of kg per tonne of grain produced, using the following parameters (Table 6). Then, these figures are multiplied by the grain yields under different rotations. The leafy fraction of stubble is estimated using the harvest index, while the grain fraction is estimated using the harvesting efficiency and losses from spilt grain. Canola stubble is not grazed.

Table 6: Parameters used in estimating stubble yields and availability

Parameter	**Cereals**	**Legumes**
Harvest index [a]	38%	30%
Harvesting efficiency	98%	90%
Losses from spilt grain	1%	1%
Proportion of leafy fraction out of total stubble biomass	33%	33%
Energy content [b] (MJ ME/kg DM) - Leafy fraction - Grain fraction	7 13.3	7 13.3
Quantity decline (%/month)	5%	5%
Quality decline (%/month)	10%	10%
Available for grazing - Leafy fraction - Grain fraction	 Jan. to May Dec. only	 Jan. toMay Dec. only
Stubble utilisation by sheep [c] - Leafy fraction - Grain fraction	 30% 80%	 30% 80%

Data sources in the above table:

a) Flood et al, 1995
b) Estimated from Rickards and Passmore, 1971
c) Ransom, 1999 pers.com.

Pasture production

The common type of pasture in the Mallee region is annual medic that regenerates naturally after a couple of years' cropping. The 'best-practice' type management is sowing medic seeds during every other pasture phase on a given paddock, ie, once every 6-8 years. Green pasture is generally available only from May to October. The monthly distribution of medic pasture production (adapted from Ransom-unpublished, Latta, 1994 and Amor, 1966) and the average monthly rainfalls are shown in Figure 1.

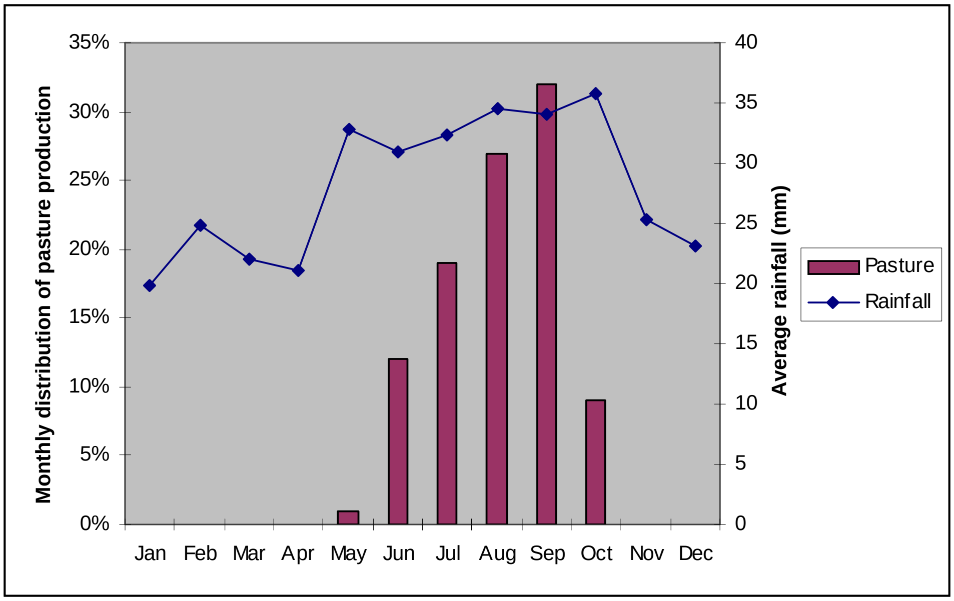

Figure 5: The monthly distribution of medic pasture production and long-term average monthly rainfalls

Quantity and quality losses occur if pasture is carried-over to the following month for later feeding. Carrying-over pasture from October to November incurs extreme losses due to leaf fall. Utilisation of green pasture is considered to be 60%. Out of the new growth of annual medic in May every year, 200 kg DM/ha is left without being grazed, to account for the amount of herbage that can't physically be eaten.

Fallowing

Commonly in the Mallee region, fallowing follows a medic pasture phase. Fallowing means the complete stoppage of crop, pasture or even weed growth for a significant period immediately before a crop is sown. The objective of fallowing had originally been to conserve moisture and break disease cycles. However, effective weed control has now become more and more important. There are two major versions of fallowing, namely, "short fallow" and "long fallow". Short fallow is practised in between two annual crops grown in two consecutive years. Long fallow is where plant growth including that of weeds is stopped and the paddock rested for a major part of the growing season and continued up to sowing a crop in the following year.

The fallow phase modelled in EMAR-Mallee is a long fallow. Long fallow results in a year without any direct income, but provides some yield benefits to the following crop. If the farm has got any livestock such as sheep, the fallow phase can provide some grazing for a part of the year. Fallowing could be done in three ways. Mechanical fallowing is done by suppressing the growth of weed plants by working the ground. Chemical fallowing is done by killing the weed plants using weedicide. The third method is by using a combination of both mechanical and chemical methods.

The method of fallowing modelled in EMAR-Mallee is a combination of mechanical and chemical fallowing methods. The initial period of this year is the same as an annual medic pasture. The pasture is sprayed in end of July, but this killed pasture could still be grazed by sheep. The ground is worked-up by the end of December, therefore, nothing is available on the paddock for grazing from January.

Sheep Production

The sheep enterprises in EMAR-Mallee are self-replacing (SR) Merino ewe, first cross (FC) ewe, Dorset over Merino (DoM) ewe and Merino (M) wethers. Depending on the expected production targets such as body weight patterns, wool and lamb production and reproduction, the monthly energy demand and the monthly DM intake capacity of the 4 sheep enterprises are estimated. The above two parameters are first estimated for each animal class (ewes of different age groups, ewe lambs, wether lambs, hoggets and rams) and then totalled for the whole flock depending on the monthly flock structure.

Generating monthly flock structure

The monthly flock structure is generated starting from 250 two-year old pregnant ewes during the month of lambing, taking the mortality rates, births, (Table 7) sales and purchases. The 12 months starting from the lambing month are later converted into calendar months depending on the lambing season chosen (May for autumn or August for spring). Lambs could be sold either in 1 or 2 batches while the selling ages of lambs could be chosen from 6 to 8 months for the first batch and from 9 to 12 months for the second batch.

Table 7: Biological parameters used in generating the monthly flock structure

Parameter	Animal class	SR Merino	FC ewe	DoM ewe	M wether
Annual mortality rate	Ewes	6%	11%	6%	
	Lambs	4%	5%	4%	
	Hoggets	3.5%	3.5%	3.5%	
	Wethers				4%
% pregnant	Mature ewes	93%	95%	93%	
	Maiden ewes	88%	90%	88%	
Lambs/ewe		1.1	1.25	1.1	

Source: Robertson, 2000 pers.com.

Estimating monthly energy demand

Monthly energy demand for an animal in each class is calculated depending on its body weight at the beginning of the month (Tables 8 to 11) and the weight change during that month.

Table 8: Monthly body weight pattern for self-replacing Merino enterprise

	Body weight in each month beginning with the lambing month											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ewe2yr	55	54	53	54	56	60	61	61	61	60	60	60
Ewe3-5yr	60	58	57	56	59	63	67	68	68	66	64	62
W.lambs				17.7	23	28.8	34.6	36.5	37.4	38.3	39.2	40.1
E.lambs				16.2	21	26.2	31.4	33.1	33.9	34.7	35.5	36.3
Hoggets	36.6	37.4	39	42	46	50	53	55	55	55	55	55
Rams	90	88	89	92	95	98	102	102	100	98	95	92

Table 9: Monthly body weight pattern for first cross ewe enterprise

	Body weight in each month beginning with the lambing month											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ewe2yr	63	61	59	57	61	65	67	68	68	67	66	65
Ewe3-5yr	65	63	61	60	64	68	71	72	72	70	68	67
W.lambs				23.4	30.6	38.5	46.4	49	50.3	51.6	52.9	54.2
E.lambs				21.5	28	35.1	42.2	44.6	45.7	46.8	47.9	48.6
Hoggets							62	63	64	64	64	64
Rams	90	88	89	92	95	98	102	102	100	98	95	92

Table 10: Monthly body weight pattern for Dorset over Merino enterprise

	Body weight in each month beginning with the lambing month											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ewe2yr	61	59	57	56	60	63	65	66	66	65	64	63
Ewe3-5yr	61	59	57	56	59	63	67	68	68	66	64	62
W.lambs				21.1	27.5	34.6	41.7	44.1	45.2	46.3	47.4	48.5
E.lambs				19.4	25.2	31.6	38	40.1	41.1	42.1	43.1	44.1
Hoggets							62	63	64	64	64	63
Rams	90	88	89	92	95	98	102	102	100	98	95	92

Table 11: Monthly body weight pattern for Merino wether enterprise

	Body weight in each month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1.5–2.5 yrs	55	55	54	53	52	51	51	53	57	60	62	63
2.5–3.5 yrs	62	60	58	56	54	53	53	55	59	62	63	63
3.5–4.5 yrs	62	60	58	56	54	53	53	55	59	62	63	63

Source for Tables 8 to 11: Robertson, 2000 pers.com.

The energy demand for an animal in each class is calculated using the following formula (Kingwell and Pannell, 1987), assuming an exercise allownace of 35% above fasting metabolism:

Energy demand = $0.39 + 0.0119\,W + 0.1305\,WC + 0.0102\,WC^2$
(LSM/head) where;

LSM: metabolisable energy (ME) expressed in terms of livestock months (Rickards and Passmore, 1977)
W: initial body weight at start of the month (kg)
WC: body weight change over the period (kg per month)

The energy demand per head is then multiplied by the number of animals in a particular class during the month. An extra energy allowance of 20% and 50% is added for the second last and the last month of pregnancy, respectively, for the proportion of ewes that are pregnant during the month. For lactating ewes, another 0.7 LSM is added (Rickards and Passmore, 1977). In order to convert the energy demand from LSM to MJ of ME, the LSM figure is multiplied by 250 MJ of ME/LSM (Rickards and Passmore, 1977).

The energy demand for the total number of animals in a particular class during the month, is then divided by the total number of breeding units (ewes) during the month of lambing for ewe enterprises and the total number of wethers in January for the wether enterprise. This is done in order to get the figures on the basis of per breeding unit, since this is the unit of the sheep enterprise in the LP matrix.

Energy demand for each animal class = LSM/head x no.of animals x MJ ME/LSM
(MJ ME/Breeding Unit/month) / no.of Breeding Units

The energy demand for a particular month as calculated above for each animal class, is then totalled to arrive at the monthly total for the flock.

Estimating monthly dry matter intake capacity

Sheep may not be able to fulfil their energy demand with low quality feed that have low energy concentrations, such as crop stubble. This is because livestock have a maximum limit of dry matter (DM) that they can take in. These DM intake capacities are calculated as follows (Kingwell and Pannell, 1987), depending on the body weight and energy concentration of the feed:

Intake = $7.8 + 1.05\,DOMD$
(g/kg body weight) where;
DOMD: digestible organic matter as a % of total DM

DM Intake Capacity = Intake (g/kg b.wt.) x $W^{0.73}$
(kg DM/day) where;
W: body weight (kg)

DM Intake Capacity = DM Intake Capacity (kg DM/day) x no.of days in the month
(kg DM/month)

DM intake capacity for each animal class is calculated as above for each month, multiplied by the number of animals and divided by the total number of Breeding Units. Then, the figures for all animal classes are totalled to arrive at the flock DM intake capacity for each month.

Appendix 2: Sensitivity of the optimal rotation to field pea and canola yields

Fp Yield t/ha	Ca Yield t/ha	Farm GM $/ha	Total Crop GM $	Sheep GM $	Optimum Rotation of the Model Run			
0.63	0.61	138	504	45	P	F	Wh	Wh
0.63	0.73	138	504	45	P	F	Wh	Wh
0.63	0.85	138	504	45	P	F	Wh	Wh
0.63	0.97	139	545	11	Wh	Ca	Wh	F
0.63	1.09	147	575	11	Wh	F	Wh	Ca
0.76	0.61	138	504	45	P	F	Wh	Wh
0.76	0.73	138	504	45	P	F	Wh	Wh
0.76	0.85	138	504	45	P	F	Wh	Wh
0.76	0.97	139	545	11	Wh	Ca	Wh	F
0.76	1.09	147	575	11	Wh	F	Wh	Ca
0.89	0.61	138	504	45	P	F	Wh	Wh
0.89	0.73	138	504	45	P	F	Wh	Wh
0.89	0.85	138	504	45	P	F	Wh	Wh
0.89	0.97	139	545	11	Wh	Ca	Wh	F
0.89	1.09	147	575	11	Wh	F	Wh	Ca
1.01	0.61	138	504	45	P	F	Wh	Wh
1.01	0.73	138	504	45	P	F	Wh	Wh
1.01	0.85	138	504	45	F	Wh	Wh	P
1.01	0.97	144	574	0	Fp	Ca	Wh	Wh
1.01	1.09	152	609	0	Fp	Ca	Wh	Wh
1.14	0.61	140	547	11	Wh	Fp	Wh	F
1.14	0.73	140	547	11	Wh	Fp	Wh	F
1.14	0.85	141	565	0	Fp	Ca	Wh	Wh
1.14	0.97	150	600	0	Wh	Wh	Fp	Ca
1.14	1.09	159	635	0	Ca	Wh	Wh	Fp