4 Crop-livestock interactions and rotation selection

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Summary

Interactions between crop and livestock enterprises are identified and described. The de Wit model of competition is presented as a suitable framework for analysing the effects of these interactions on farm profit. It is found that interactions do have an impact on potential farm profit and the selection of rotations. The effect is accentuated if lupins are excluded from the farm. It is concluded that for this farming system interactions should be included in economic analyses of alternative land uses.

4.1 Introduction

In the past economic analyses of dryland farming in Western Australia have commonly been based on simple procedures such as gross margins analysis (e.g. Ripley, 1984). These analyses have usually treated crop and livestock enterprises as simple competitors for land, largely ignoring complexities of the farm system including interdependencies of enterprises.

On the other hand, there are available a number of dynamic simulation models of farm enterprises (e.g. White et al., 1983) which treat in detail the biology and technology of individual enterprises but again do not consider interactions between enterprises.

In the development of MIDAS an attempt was made to combine a whole farm approach with a relatively detailed representation of the system's biology, technology and resources. Emphasis was placed on the identification and representation of enterprise interactions. This chapter is an investigation of the effects which enterprise interactions have on profit and the selection of enterprises.

4.2 Description of interactions

For the purposes of this analysis interactions are defined as characteristics of a system which cause its components to behave differently in combination than one would expect based solely on their behaviour in isolation. For example it is common for mixed swards of pasture plants to yield differently than the weighted sum of monoculture yields (Trenbath, 1974).

In the agricultural system represented by MIDAS there are a number of interactions between enterprises. This chapter focuses on those between cereal crop and livestock. Only interactions occurring within the model farm are examined. Interactions at the level of the farming community, the state or region (Hart, 1985) are not included in the analysis. The interactions considered are described in the following subsections.

4.2.1 Biological nitrogen fixation

Pasture legumes such as subterranean clover (*Trifolium subterraneum*) and medics (*Medicago* spp.) can convert atmospheric nitrogen into biological nitrogen compounds. When these annual legumes break down, nitrogen is released into the soil and becomes available to subsequent non-legume crops, increasing their yield and/or reducing the need for nitrogen fertilizers. This is a positive interaction as the total yield and profitability of a cereal-legume pasture rotation are higher than a combination of crop and pasture monocultures. The assumed levels of fixed nitrogen available to crops in different situations are shown in Table 4.1

Table 4.1 Fixed nitrogen available to cereal crops from previous pasture (kg N/ha).

	Poor light soil	Good light soil	Medium soil	Heavy soil
First crop after one year pasture	2	5	5	25
Second crop after one year pasture	2	3	0	25
First crop after two years pasture	4	6	10	25
Second crop after two years pasture	3	3	1	25

4.2.2 Other benefits of pasture for cereal crops

Apart from nitrogen fixation there are several other mechanisms by which pastures can improve the yields of cereal crops. These include disease break effects and soil structure effects. If a crop is grown for several years in succession on a particular area, the level of fungal or bacterial disease can build up and reduce yield. By breaking the run of years of crop with one or more years of pasture, diseases specific to the crop can be reduced. It is likely that the same effect operates in reverse for pasture, but it is dominated by the negative effect of cropping on pasture production (Subsection 3.2.4). It is possible that pastures also improve soil structure leading to improved crop root structure and subsequent yield increases. This remains unproven, however, at least in the Western Australian environment. The proportion of cereal yield boost following pasture and attributable to these and other possible mechanisms is not known. However in order to calculate the relative profitabilities of alternative rotations, all that is needed is the magnitude of the sum of the effects (Table 4.2).

Table 4.2 Cereal yield boost from factors other than fixed nitrogen (kg/ha).

	Poor light soil	Good light soil	Medium soil	Heavy soil
First crop after one year pasture	150	250	200	50
Second crop after one year pasture	100	150	100	50
First crop after two years pasture	175	350	200	50
Second crop after two years pasture	100	250	125	50

4.2.3 *Weed control costs*

Pastures contain many species which are weeds in subsequent crops. The number and species of weeds in a crop depend on firstly, the number of years since a pasture has been grown on that area and secondly, the density and composition of that pasture which in turn depend on the number of consecutive years of pasture. Different weed species require different herbicides for effective control and different weed densities lead to changes either in rate or brand of herbicide. Consequently the cost of weed control in a crop depends largely on crop and pasture history. In some rotations crop and pasture interact negatively with regard to herbicide costs, while in others the interaction is positive (Table 4.3).

Table 4.3 Average cost of weed control chemicals ($/ha).

Rotation*	Poor light soil	Good light soil	Medium soil	Heavy soil
PPPP	2.17	2.17	2.17	2.17
PPPC	1.78	1.78	1.78	1.58
PPC	2.37	2.37	2.37	2.10
PCPC	3.55	3.55	3.55	3.49
PPCC	6.93	6.93	6.93	6.93
PCC	9.23	9.23	9.23	9.23
PCCC	9.51	9.51	9.51	9.51
CCCC	9.23	9.23	9.23	9.23

* C = Cereal crop; P = pasture.

4.2.4 *Pasture production following cropping*

During a year of crop, pasture plants within the crop may be killed by cultivation or the application of herbicides. This reduces seed production in that year and depletes the store of dormant seeds produced in previous years leading to reduced pasture production in the subsequent year. The effect is exacerbated by the relatively high sensitivity of pasture legumes to years of cropping and compounded further if crops are grown in consecutive years (See Table 4.4 for the assumed effects of cropping on pasture production).

Table 4.4 Proportion of maximum pasture production (MPP) lost following cropping (%).

Soil type	Years of crop (yr)	Reduction in MPP in May-July (%)	Reduction in MPP in August-November (%)
Poor light	1	50	25
	2	60	40
	3+	70	55
Good light	1	50	25
	2	60	40
	3+	70	55
Medium	1	37.5	12.5
	2	45	20
	3+	52.5	27.5
Heavy	1	25	0
	2	30	10
	3+	35	20

4.2.5 Grazing of cereal residues

Interactions described in Subsections 4.2.1 to 4.2.4 are all interyear effects, i.e. they are effects which one enterprise has when the other is run in subsequent years on the same area. There is also an interaction which occurs within one season across different areas of the farm; the grazing by livestock of crop residues. Because pasture is mainly available in winter and spring while crop residues are available in summer, they can be conveniently combined as feed sources for livestock. This is another positive interaction between the enterprises.

4.3 The de Wit model of competition

De Wit (1960) developed a model to analyse the results of competition experiments. The model has been widely adopted and applied by ecologists, experimental biologists and agricultural scientists (e.g. de Wit & van den Bergh, 1965; de Wit et al., 1966; Baeumer & de Wit, 1968; van den Bergh, 1968; Hall, 1974a & 1974b; Berendse, 1979 & 1981; Gilbert & Robson, 1984). In a comparison of different models of competition, Trenbath (1978) concluded that de Wit's is the most suitable for ecological purposes. In this chapter, crop-pasture interactions are analysed using a method which owes much to the ideas of de Wit.

4.3.1 Outline of de Wit model

De Wit was primarily concerned with competition, defined as simultaneous demands by individuals for resources, which mutually reduce their growth or reproductive capacity. On the other hand, the word 'interactions' captures all influences that individuals have on each other, whether positive or negative, direct or indirect (Braakhekke, 1980). Since the de Wit model can analyse positive and negative effects and this analysis is concerned with both, the term 'interactions' is used throughout.

Interactions can best be studied in 'replacement series' experiments in which yields of monocultures of equal density are compared with yields of mixtures of each species with the same total plant density. Results are plotted as shown in Figure 4.1. Figure 4.1a shows the replacement diagram for two species which give a better total yield in a mixture than a weighted combination of monoculture yields. This may be due to active complementary interactions such as stimulation or protection, or it may result from a dominance of intraspecies competition over interspecies competition. Figure 4.1b illustrates results for two species which have neither interspecific nor intraspecific interactions. Alternatively there may be a balance of positive and negative, inter- and intraspecific interactions. Figure 4.1c illustrates two species antagonistic towards each other due to active interference by mechanisms such as allelopathy.

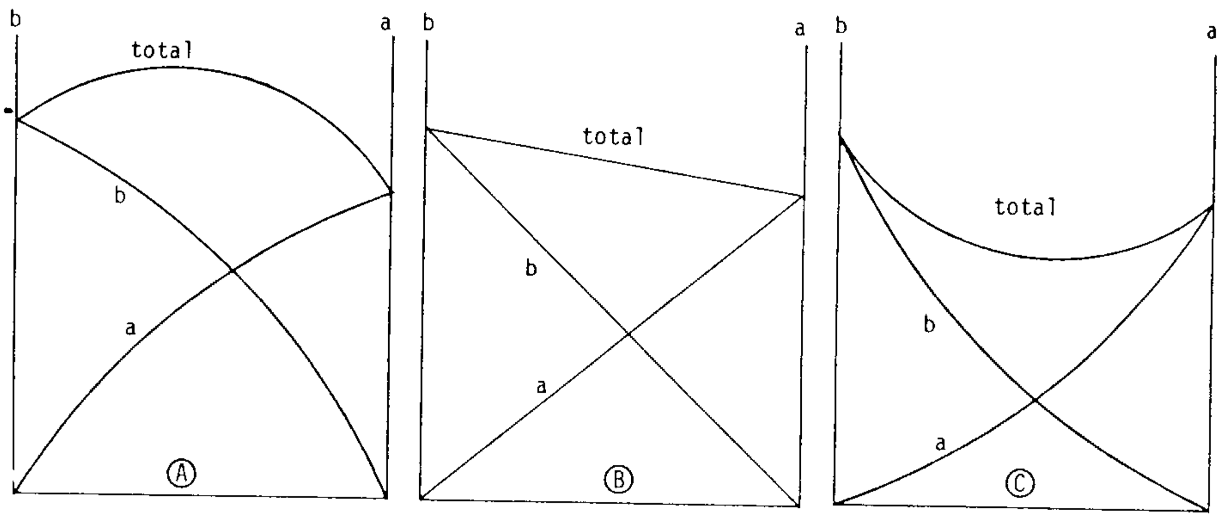

Figure 4.1 Replacement diagrams for species a and b. (a) Interspecies complementarity or interspecies competition dominated by intraspecies competition; (b) Species non-interactive or interspecies competition matched by intraspecies competition; (c) Negative interactions between species.

4.3.2 Application to farm enterprise comparison

This analysis differs from the usual de Wit replacement series in a number of respects. We are concerned not with mixed swards, but with mixed farms, not only with yield but with profit from whole enterprises, not with direct physical interactions within one year, but with indirect interactions on profit which may occur across soil types or between years, not with varying individual density while holding total density constant, but with varying areas of each enterprise with a constant total area. However, despite these differences the method of analysis is fundamentally the same. The model is solved repeatedly for different areas of crop and pasture. That is, MIDAS is constrained to find the optimal farm plans which include 2300 ha of crop and no pasture, 1840 ha crop and 460 ha pasture and so on through to no crop and 2300 ha pasture. Results are plotted on a replacement diagram. This is repeated with and without crop-pasture interactions represented, the difference in results being attributable to the interactions. The process of revising the model (e.g. constraining it to a particular crop:pasture ratio or deleting interactions) is described in Section 3.4. Revision data used in this analysis are given in Section D.1 of Appendix D.

4.4 Results and discussion of analysis

If all resources and farm inputs were homogeneous and perfectly divisible and there were no interactions between crop and pasture, there would be a linear relationship between profit and the percentage of the farm in crop. This situation is similar to the total yield curve in Figure 4.1b. If there were homogeneous and perfectly divisible resources and inputs combined with positive interactions between crop and pasture, profit would vary with cropping percentage in a manner similar to that shown in Figure 4.1a whereas negative interaction would give the result shown in Figure 4.1c.

In the real world, even with no interactions there would not be a linear relationship between cropped area and profit. This is because some inputs are indivisible (machinery), there are progressive marginal tax rates, interest rates increase with increasing debt, resources are not homogeneous and there are returns to scale in some aspects of the farm (machinery and sheep overheads).

When these factors are included but crop-pasture interactions are excluded the relationship between cropping percentage and profit it as shown by the lower curve in Figure 4.2. There is a decline in profit moving from zero to 10 per cent cropping due to the indivisibility of cropping machinery. Thereafter profit increases at a decreasing rate (due to increasing marginal tax and interest rates and decreasing favourability of soil for cropping) to a maximum between 80 per cent and 100 per cent cropping. The upper curve in Figure 4.2 shows results for the standard model with interactions included. The net effect of interactions is positive, i.e. they result in an increase in profit. The increase is

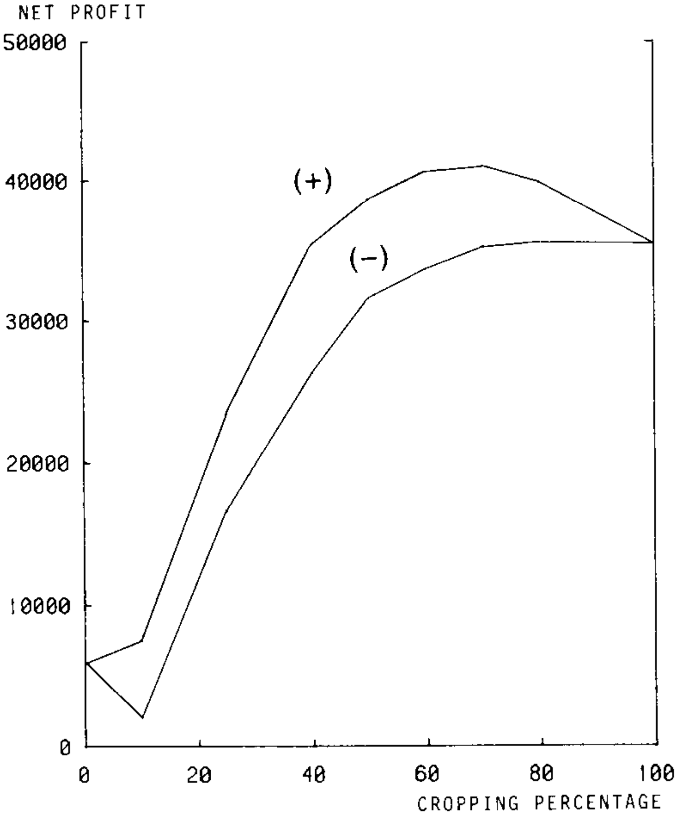

Figure 4.3 Replacement diagrams for crop and pasture with (+) and without (−) interactions if no lupins.

largest where there is an approximately even split of land between crop and pasture, and it decreases to zero at each extreme, no crop or 100 per cent crop. This results in a reduction in the profit maximising cropping percentage from 80-100 per cent to 60-70 per cent. The optimal farm plans with and without interactions are summarised in Table 4.5. Optimal rotations differ on heavy and poor light soils. The exclusion of interactions results in selection of rotations with more crop on each of these soils.

For farmers adopting the farm plan selected as optimal by MIDAS, crop-pasture interactions have a moderate effect on profit and lupins form a major part of the plan. However lupins are a relatively new crop (Chapter 6) and many farmers grow little or none. To investigate the extent to which lupins affect the results of this study, the analysis is repeated with lupin rotation options removed from the model. Figure 4.3 shows the resulting replacement diagrams with and without interactions. Without lupins the value of pasture-crop interactions is greatly increased as indicated by the greater difference between curves in Figure 4.3 than in Figure 4.2. The reason for the difference is that when lupins are included, it is more profitable to put cereal crop in rotation with lupins than with pasture, so the pasture grown tends to be in continuous stands. In this situation the only crop-pasture interaction of benefit to the farmer is livestock grazing both pasture and crop residues (4.2.5). When lupins

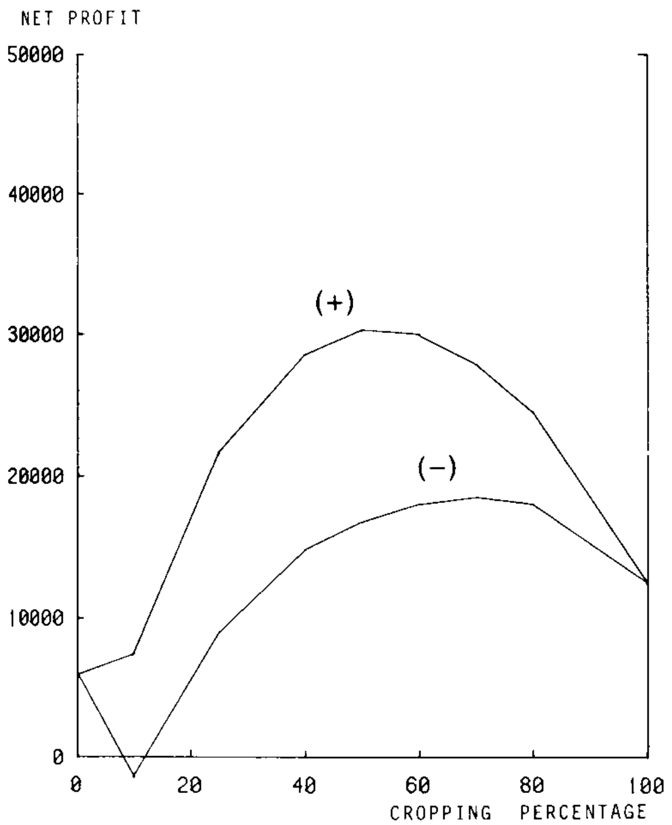

Figure 4.2 Replacement diagrams for crop and pasture with (+) and without (−) interactions.

are removed they are replaced by crop-pasture rotations and the full range of interactions occurs.

As was the case when lupins were included, one effect of crop-pasture interactions is to reduce the optimal area of crop, in this case from 70 per cent to 56 per cent of the farm. The corresponding optimal farm plans (with no lupins) are shown in Table 4.6. Apart from the lower area of crop when interactions are included, another trend is the selection of rotations including both crop and pasture. Without interactions there is a tendency for MIDAS to select continuous cropping and continuous pasture. Without lupins the difference between potential profit with and without interactions is $8340 (Table 4.6) whereas with lupins included the difference is only $3110 (Table 4.5).

Table 4.7 shows shadow costs of medium land rotations in the farm plans presented in Table 4.6. The shadow cost is the difference between an activity's current objective function value and the value which would bring the activity into the optimal solution (see Subsection 3.2.2). Interactions have a substantial effect on the relative profitabilities of different rotations. Without interactions the optimal rotation is CCCC (continuous cropping) whereas with interactions this is surpassed by PCC, PCPC, PCCC and PPCC. Without interactions the shadow cost is almost linearly related to the proportion of crop in the rotation whereas with interactions crop-pasture rotations are most profitable and the extremes of all crop or all pasture perform comparatively poorly.

Table 4.5 Optimal farm plans with and without crop-pasture interactions.

Interactions	Included	Excluded
Profit ($)	41 250	38 140
Sheep (d.s.e.)*	3 578	1 062
Rotation selected**		
Poor light soil	PPPC	CCL
Good light soil	CCL	CCL
Medium soil	CCL	CCL
Heavy soil	PPC	PPC

* d.s.e. = dry sheep equivalents.
** C = cereal crop; P = pasture; L = lupins.

Table 4.6 Optimal farm plans with and without crop-pasture interactions if lupins excluded.

Interactions	Included	Excluded
Proft ($)	30 720	22 380
Sheep (d.s.e.)*	3 625	2 833
Rotation selected**		
Poor light soil	PPC	PPPP
Good light soil	PPCC	CCCC
Medium soil	PCC	CCCC
Heavy soil	PCC	PCC

* d.s.e. = dry sheep equivalents.
** C = cereal crop; P = pasture; L = lupins.

Table 4.7 Shadow costs of medium land rotations with and without crop-pasture interactions if lupins excluded ($/ha).

Interactions included		Interactions excluded	
Rotation*	Shadow cost	Rotation*	Shadow cost
PCC	0	CCCC	0
PCPC	0.11	PCCC	1.56
PCCC	1.39	PCC	2.06
PPCC	1.89	PPCC	4.98
CCCC	3.00	PCPC	5.80
PPC	3.48	PPC	8.42
PPPC	5.93	PPPC	9.75
PPPP	14.89	PPPP	13.71

* C = cereal crops; P = pasture.

4.5 Conclusion

Interactions can have a marked effect on the results of economic analyses of Western Australian wheatbelt farms and so should be included in such analyses. Interactions affect not only potential profit but also the selection of optimal rotations and the order of profitability of alternative rotations. The importance of interactions can vary widely in some circumstances such as the inclusion or exclusion of lupins from the farm plan. These results suggest that the emphasis on interactions in MIDAS is justified and that a wholefarm framework, rather than a partial or piecemeal approach should be used for enterprise comparisons in the modelled region.