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## COMBINING BIOPHYSICAL AND PRICE SIMULATIONS TO ASSESS THE ECONOMICS OF LONG-TERM CROP ROTATIONS

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### Abstract

Biophysical simulation models (e.g. APSIM) using historical rainfall data are increasingly being used to provide yield and other data on crop rotations in various regions of Australia. However, to analyse the economics of these rotations it is desirable to incorporate the other main driver of profitability, price variation. Because the context was that APSIM was being used to simulate an existing trial site being monitored by a farmer group Gross Margin output was considered most appropriate. Long-run rotational gross margins were calculated for the various rotations with yields (and other physical outputs) derived from APSIM simulations over a period of 100+ years and prices simulated in @Risk based on subjective triangular price distributions elicited from farmers in the group.

Rotations included chickpeas, cotton, lucerne, sorghum, wheat and different lengths of fallow. Output presented to the farmers included mean annual gross margins and distributions of gross margins presented as probability distributions, cumulative probability distributions and box and whisker plots. Cotton rotations were the most profitable but had greater declines in soil fertility and greater drainage out of the root zone.

### Introduction

This study was conducted with a farmer group on the Jimbour Plain of Queensland. The Jimbour Plain is north of Dalby in SE Queensland and has an annual rainfall of 676mm. The soils are deep, self-mulching black vertosols and the main crops in the area are dryland and irrigated cotton, maize, wheat, barley, sorghum, chickpea, mungbean and sunflower. The group had an existing trial looking at various rotations and management systems and were familiar with simulation modelling of the biophysical system using APSIM or Agricultural Production Systems Simulator (Keating and McCown 2001). APSIM is a farming systems simulator that combines climate risk analysis with the prediction of long-term consequences of farming practice on the soil resource.

Farmers involved in this project were interested in the long-term benefits and costs of the various rotations with and without lucerne. This paper addresses the issue of developing a method of analysis for the information generated from these simulations that could be presented to farmers so that it allowed them to assess the returns and risks associated with each of the rotations. The main risks to be considered were yield and price risk, although sustainability indices such as subsoil drainage and run-off were included as well.

### Economics of perennial and long-term rotations

Bathgate and Pannell (2002, p. 118) point out that 'high quality economic analysis of perennial plant-based enterprises is not straightforward'. This is because of the complexities of interactions between crops including the complementary and supplementary effects, the trade-offs between short-term returns and long-term sustainability factors, and the various options for incorporating perennials such as lucerne in the cropping systems.

Another complicating factor is that lucerne on the Jimbour Plain has to be incorporated in rotations that include chickpeas, cotton, mungbeans, sorghum, wheat and different lengths of fallow. More importantly these crops have different sowing windows, moisture requirements, climatic responses and different price levels and variations. Consequently there are different levels of profitability and risk associated with the crops and rotations that can influence the decision to adopt a rotation. Some crops may be cropped opportunistically (i.e. not growing a crop if there is insufficient stored soil moisture) while others such as cotton require substantial fallow periods to be successful.

### Farmer decision making

The context of this study was that farmers were attempting to incorporate lucerne in their rotations to lift the long-term profitability of the cropping operations by improving soil properties. There is also an element of improving environmental sustainability of their operations by decreasing run-off and subsoil drainage.

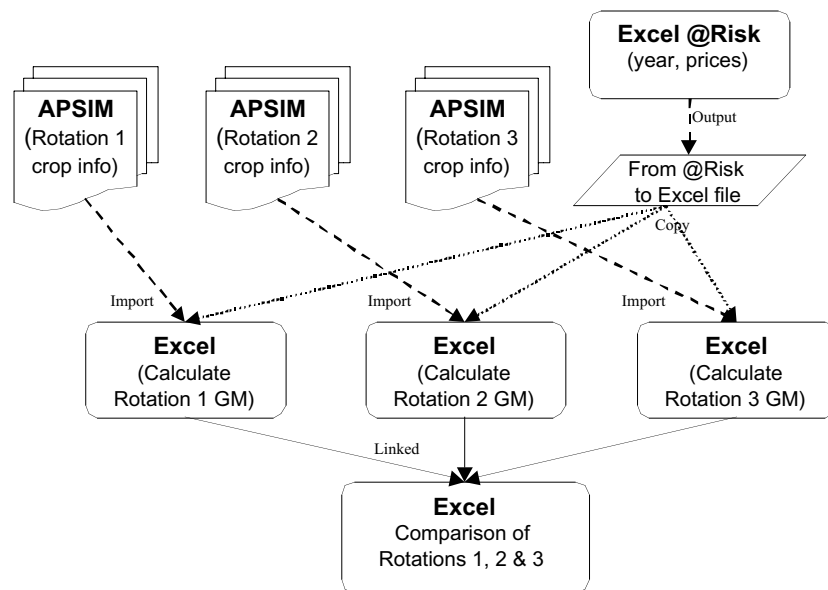
Risk preferences also influence farmers' decisions. There is strong evidence that Australian farmers are risk averse (Bond and Wonder 1980; Abadi Ghadim and Pannell 2000). This means farmers take account of the variability of return as well as the level of return and accept lower returns in order to reduce their risks. There is also evidence that people respond differently in situations of Knightian uncertainty and ambiguity (Camerer and Weber 1992; Murray-Prior and Wright 2001). Consequently the decision to make a particular strategic change in a cropping rotation will depend upon the context set by the manager's higher-level strategies. The relationship between these factors will interact with the riskiness of the particular decision and the manager's attitude to risk.

Since the purpose of this study was to provide information that could be used in a discussion with farmers, the information provided needed to be in a form that farmers could easily incorporate in their decision processes (Murray-Prior 1996). This implied separating level of profitability, variability of profitability and sustainability factors so that farm managers could evaluate trade-offs between these factors according to their own preferences.

### Method

The analysis was conducted in four steps: Simulating biophysical data in APSIM, simulating prices in @Risk, combining these simulations to calculate rotational gross margins in Excel spreadsheets and finally comparing various rotational choices in an additional Excel spreadsheet (Figure 1).

**Figure 1: Representation of stages in calculating rotational gross margins and comparing rotations**



### Selection of rotations to be analysed

Following discussions with the Jimbour farmers' group, 12 rotations were selected for analysis. Seven of these rotations were traditional rotations and the remaining five included lucerne (for hay) in a traditional rotation (Table 1). The traditional rotations can also be divided into those that incorporate dryland cotton (cotton rotations) and those that don't include cotton (grain rotations). Rotations vary in length from two to ten years. In simulating crop production and in calculating the rotational gross margins it was assumed that the area to be analysed was divided into a number of equal paddocks based on the number of years in the rotation and that each component of the rotation was represented in each year. Consequently, a three-year rotation assumed three paddocks and a ten-year rotation assumed ten paddocks.

**Table 1: Rotations considered in the analysis**

Rotation 1: Wheat-chickpea Cotton-sorghum	Rotation 2: Sorghum-chickpea	Rotation 3: Cotton-wheat	Rotation 4:
Rotation 5: Cotton-wheat/f	Rotation 6: Cotton-wheat (2 year)	Rotation 7: Cotton-sorghum (3 year)	Rotation
8: Lucerne-wheat-chickpea			

Rotation 9: Lucerne-sorghum-chickpea    Rotation 10: Lucerne-cotton-wheat    Rotation 11: Lucerne-cotton sorghum    Rotation 12: Lucerne-cotton-wheat/f

■ : Indicates the end of a rotation

### Biophysical modelling of rotations in APSIM

APSIM was initiated using the starting parameters. The long term simulations provided over 100 years of crop yields for a continuous rotation, along with protein levels where appropriate, and the sustainability indicators of run-off, subsoil drainage and humic N (non-labile nitrogen pool). Model results were validated against five years of trial data (Dalgliesh 2001). The economic analysis was conducted on the information for the years 1900 to 1999 inclusive.

### Economic modelling

In step two, price variability was estimated by the farmer group using triangular distributions of long-run prices for the various crops and for urea. Price distributions for the crops and urea were simulated in @Risk (ver. 4.0) for 1000 iterations.

The method chosen for combining APSIM and @Risk results was, for each iteration of prices, to select a year from the period 1900 to 1999 using the Discrete distribution in @Risk. The results from each of the 1,000 iterations therefore contained random, probability-weighted selections incorporating a year of production along with crop and urea prices selected from the assumed distributions.

Step three involved combining the APSIM output and the @Risk output to calculate each rotational gross margin. This was calculated in a series of steps. For each of the 1,000 iterations, a gross margin was calculated for each stage in the rotation. For example the two-year cotton/wheat rotation (Rotation 6) included calculations of gross margins for winter wheat, summer fallow, winter fallow and summer cotton. This was averaged to give the gross margin for that iteration. These gross margins were used to calculate the average gross margin for the rotation over the 1000 iterations and the distribution of gross margins for the rotation.

Statistics calculated for each rotation gross margin included: Mean, Median, Maximum, Minimum, Standard deviation, Skewness, Kurtosis and Percentiles. Results for a rotation were graphed in three formats, probability distribution, cumulative probability distribution and box and whisker plot.

The main sustainability criteria modelled in APSIM were humic N, runoff and drainage. These were used to calculate final humic N (the average humic N for the final year of analysis, 1999), and average runoff and average drainage (averages calculated as average of each year's average runoff).

### Presentation of results to farmers and agribusiness

Step four involved linking information on rotations so that they could be compared and presented to the farmers' group. To avoid confusion and cognitive overload a maximum of five rotations were compared graphically at any one time. Preliminary results were discussed with the farmer's group and adjustments made to some rotations, costs, input levels and presentation formats. The final results were presented to the farmer's group and agribusiness representatives associated with the group.

### Calculation of efficiency measures

For this paper, the rotations were also compared using mean-standard deviation and first and second-degree stochastic dominance. First and second-degree stochastic dominance comparisons were made using the discrete method and pair-wise comparisons based on the fractile results. A rotation was considered to be second-degree stochastic dominant of another rotation using the following criteria from Anderson, Dillon and Hardaker (1977): mean greater, minimum  $\geq$ , and the discrete equivalent of the area under its cumulative distribution function smaller.

### Results

The results presented here summarise key outputs of mean rotational gross margins, variation in and riskiness of these gross margins, the effect of lucerne on the rotations and environmental sustainability comparisons.

- Mean gross margins

Mean rotational gross margins ranged from just under \$300/hectare for the Lucerne-sorghum-chickpea rotation to slightly over \$800/hectare for the high intensity Cotton-wheat (2 year) rotation. As expected the cotton rotations had higher gross margins than the grain rotations (Table 2). On this basis, the best performing cotton rotation (Rotation 6: Cotton-wheat (2 year)) had an average gross margin of \$805/hectare; double that of Rotation 1 (Wheat-chickpea) at \$402/hectare. There was little difference between the grain rotations (Rotation 2: Sorghum-chickpea and Rotation 1: Wheat-chickpea) however the Cotton-wheat rotations had slightly higher gross margins (approximately \$100/hectare) than the Cotton-sorghum rotations.

**Table 2: Rotational gross margin results**

	Rotation											
	1	2	3	4	5	6	7	8	9	10	11	12
<b>Mean</b>	402	415	721	628	731	805	649	302	299	490	527	593
<b>Median</b>	393	430	742	616	733	767	643	291	292	479	523	586
<b>SD</b>	329	255	569	335	559	650	372	255	256	339	338	545
<b>Min</b>	-356	-332	-723	-455	-723	-869	-490	-266	-268	-303	-445	-572
<b>20%</b>	86	208	317	384	333	352	351	64	58	201	279	141
<b>80%</b>	700	633	1,19	897	1,16	1,31	956	545	552	787	788	1,07
<b>85%</b>	770	693	1,29	975	1,28	1,49	1,03	591	605	838	840	1,17
<b>Max</b>	1,32	1,08	2,25	1,63	2,54	3,26	1,86	962	832	1,44	1,48	2,25
<b>Skewness</b>	0.16	-0.34	-0.30	-0.21	-0.10	0.05	-0.03	0.13	-0.02	0.16	-0.13	0.01
<b>Kurtosis</b>	-0.58	0.11	0.13	0.82	0.31	0.58	0.45	-0.73	-0.86	-0.33	0.22	-0.44

Rotation 1: Wheat-chickpea

Rotation 4: Cotton-sorghum

Rotation 7: Cotton-sorghum (3 year)

Rotation 10: Lucerne-cotton-wheat

Rotation 2: Sorghum-chickpea

Rotation 5: Cotton-wheat/f

Rotation 8: Lucerne-wheat-chickpea

Rotation 11: Lucerne-cotton sorghum

Rotation 3: Cotton-wheat

Rotation 6: Cotton-wheat (2 year)

Rotation 9: Lucerne-sorghum-chickpea

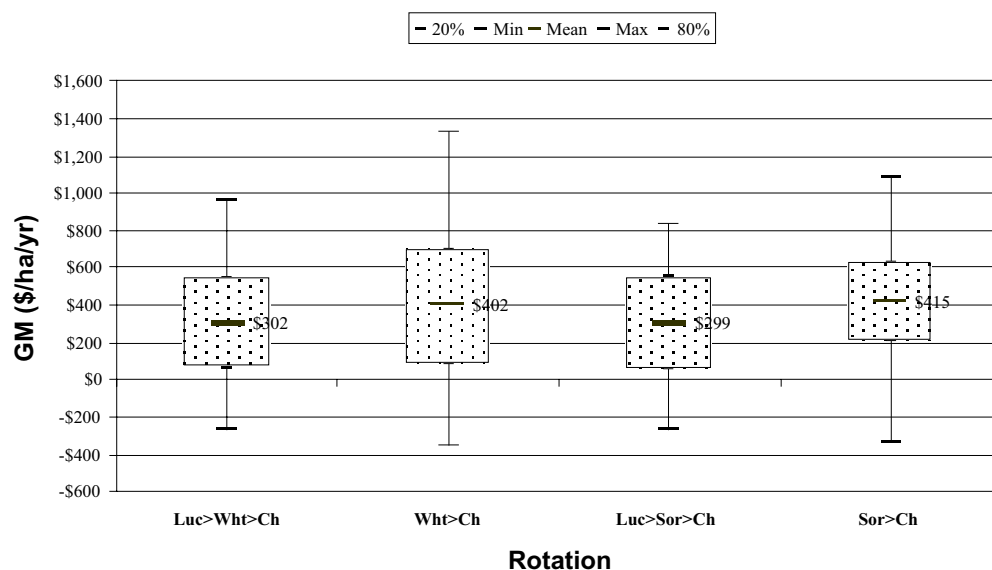
Rotation 12: Lucerne-cotton-wheat/f

As indicated by the mean-median differences and the skewness measures, the gross margins are not particularly skewed. Similarly there is no consistent kurtosis pattern although the cotton rotations are all positive indicating slightly longer tails.

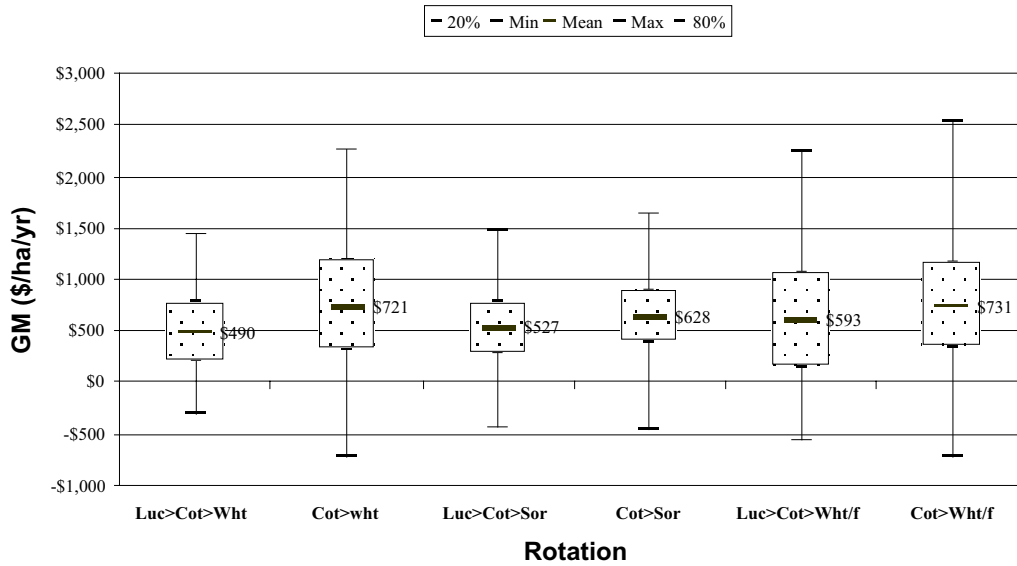
### Effect on mean gross margins of adding lucerne to rotations

The effect of adding lucerne was to decrease the rotational gross margin by approximately \$100/hectare (slightly more for the cotton-wheat rotations) while decreasing the dispersion of income (Figure 2; Figure 3). In all cases except for the cotton-sorghum rotations, the lucerne also decreased the downside risk as measured by the minimum gross margin.

**Figure 2: Boxplot of grain rotations with and without lucerne**



**Figure 3: Boxplot of cotton rotations with and without lucerne**



### Riskiness of rotations

In general, the higher the mean gross margin, the higher the dispersion of gross margins (Table 2). This can be represented in mean-standard deviation space (Figure 4) to determine the efficient set according to the criteria for mean standard deviation efficiency (Hardaker, Huirne and Anderson 1997). On this basis the mean-standard deviation efficient set of rotations are Rotation 6 (Cotton-wheat (2 year)), Rotation 5 (Cotton-wheat/f), Rotation 7 (Cotton-sorghum (3 year)), Rotation 4 (Cotton-sorghum) and Rotation 2 (Sorghum-Chickpea). None of the lucerne rotations are in the efficient set.

**Figure 4: Rotations<sup>a</sup> in mean-standard deviation space**

<sup>a</sup> Numbers correspond to rotation numbers in Tables 1 & 2.

First and second-degree stochastic dominance measures also provide a measure of efficient sets. The results for second-degree stochastic dominance are shown in Table 3. In this case Rotation 10 (Lucerne-Cotton-Wheat) dominates Rotation 1 (Wheat-Chickpea) by first-degree stochastic dominance. Using second-degree dominance Rotation 8 (Lucerne-wheat-chickpea) dominates Rotation 9 (Lucerne-sorghum-chickpea), Rotation 10 (Lucerne-cotton-wheat) > Rotation 2 (Sorghum-chickpea), Rotation 2 (Sorghum-chickpea) > Rotation 1 (Wheat-chickpea), Rotation 4 (Cotton-sorghum) > Rotation 12 (Lucerne-cotton-wheat/f) and Rotation 7 (Cotton-sorghum (3 year)) > Rotation 12 (Lucerne-cotton-wheat/f).

**Table 3: Pair-wise comparison matrix<sup>a</sup> showing results of second degree stochastic dominance analysis<sup>b</sup> of rotations**

	Rotation <sup>c</sup>											
	1	2	3	4	5	6	7	8	9	10	11	12
1	*	-	?	?	?	?	?	?	?	-	?	?
2	+	*	?	?	?	?	?	?	?	-	?	?
3	?	?	*	?	?	?	?	?	?	?	?	?
4	?	?	?	*	?	?	?	?	?	?	?	+
5	?	?	?	?	*	?	?	?	?	?	?	?
6	?	?	?	?	?	*	?	?	?	?	?	?
7	?	?	?	?	?	?	*	?	?	?	?	+
8	?	?	?	?	?	?	?	*	+	?	?	?
9	?	?	?	?	?	?	?	-	*	?	?	?
10	+	+	?	?	?	?	?	?	?	*	?	?
11	?	?	?	?	?	?	?	?	?	?	*	?
12	?	?	?	-	?	?	-	?	?	?	?	*

<sup>a</sup> + = Rotation in row dominates column; - = Rotation in row is dominated by column; ? = Rotation in row neither dominates nor is dominated by column.

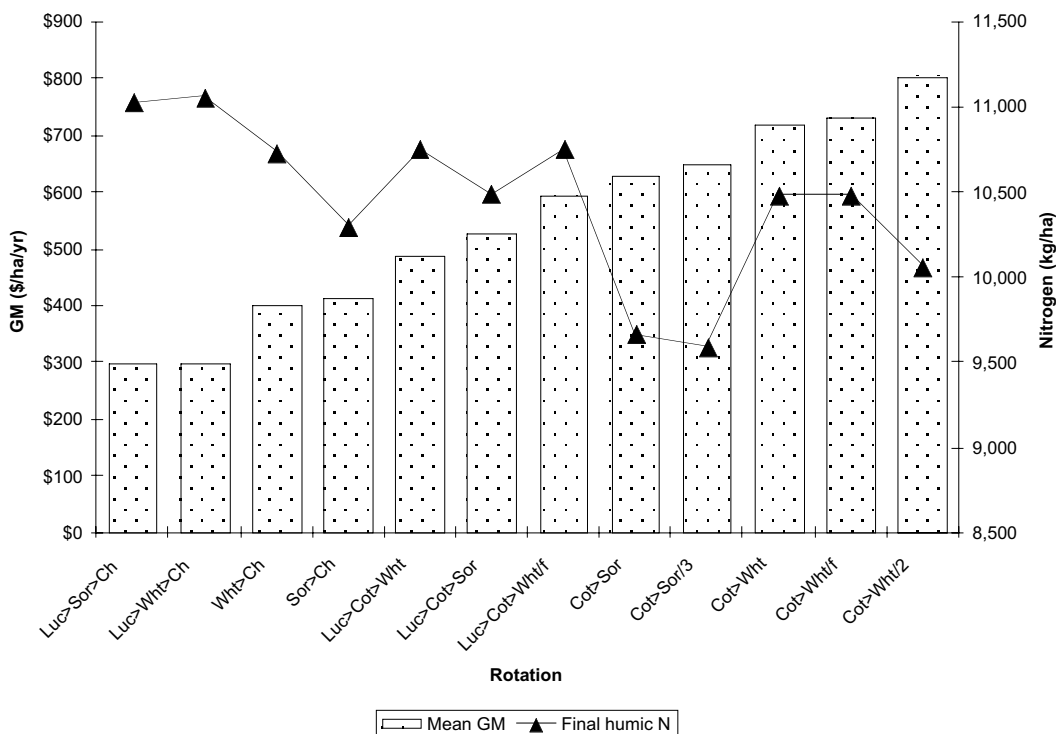
<sup>b</sup> Analysis based on discrete method using fractile values in Table 2.

<sup>c</sup> Numbers correspond to rotation numbers in Tables 1 & 2.

### Environmental sustainability comparisons

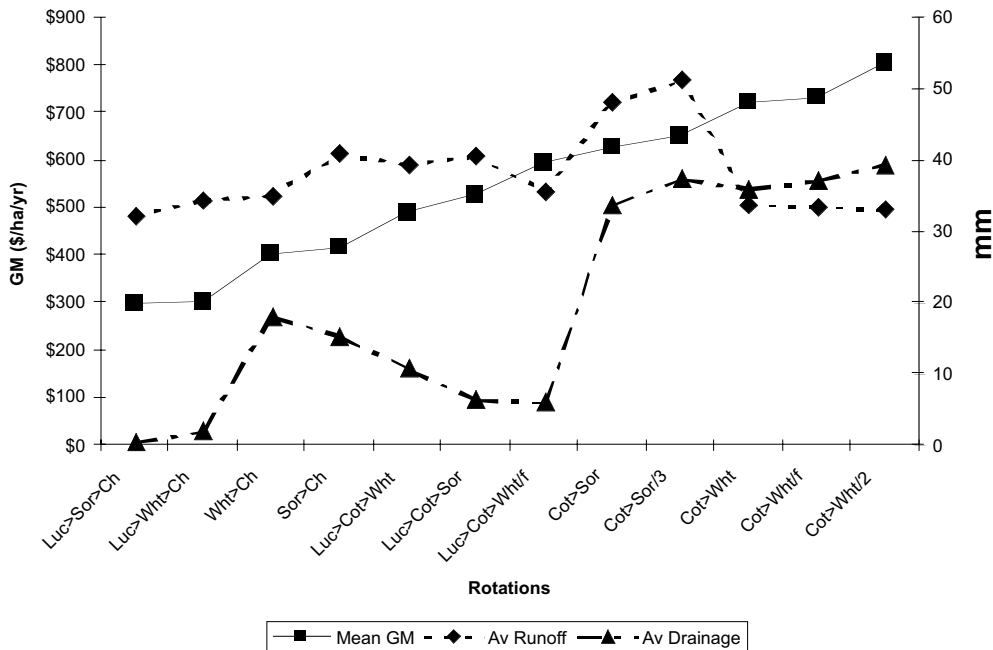
An inverse relationship was found between mean gross margin and final humic N (Figure 5). Thus the lucerne grain rotations had the highest final humic N but also had the lowest mean gross margin. In contrast cotton-sorghum rotations had the lowest final levels of humic N and amongst the highest gross margins. Sorghum dominant rotations performed more poorly than their wheat dominant equivalents with respect to final humic N levels.

**Figure 5: Mean gross margins of rotations versus final humic N**



A similar result was found for drainage, as the rotations with higher mean gross margins tended to have higher average drainage levels (Figure 6). Lucerne-grain rotations had almost non-existent drainage levels while lucerne-cotton-grain rotations had low levels. Cotton rotations (without lucerne) had drainage levels more than double the highest levels for other rotations.

**Figure 6: Mean gross margins of rotations versus average runoff and drainage**



The relationship between mean gross margin and average runoff was less obvious although runoff tended to increase with increase in gross margin for all except the highest performing cotton-wheat rotations. Lucerne does not appear to have made much difference to runoff although rotations with lucerne tended to have slightly lower runoffs when compared with their equivalent rotations without lucerne.

## Discussion

Three main issues are addressed in the discussion: the strengths and weaknesses of the methodology, a comparison of the rotations including some policy implications, and the appropriateness of various methods for presenting the data to farmers.

### Assessment of methodology

The methodology and associated spreadsheets outlined in this paper appear to have achieved the objective of providing suitable information to help farmers and agribusiness professionals assess and select long-term rotations that include a perennial phase. It allows for the incorporation of detailed biophysical simulation results with minimal effort, which means that when changes are made to the simulation they can be easily incorporated.

Weaknesses include that it is limited to the soil type and conditions used in the simulation model, and therefore does not indicate the optimum combinations of rotations for the farm. Labour, machinery and financial constraints also need to be considered by the decision maker in selecting the optimal rotation.

### Choice of rotations

Under the assumptions of this model, lucerne is not a profitable rotation for the Jimbour Plains reducing the GM by \$100/hectare or more when compared with rotations that do not include it. The effect is greater for cotton rotations. However, it does contribute to soil fertility and almost eliminates drainage from the bottom of the profile, although these are not big problems on the Jimbour plains.

Conversely, cotton is the most profitable rotation with almost all the rotations in the mean-standard deviation efficient set being cotton rotations. However, cotton rotations tended to have higher income variance and the largest downside risk with lower minimum gross margins. Cotton-grain rotations also had higher drainage levels from the bottom of the profile (approximately doubling drainage) and also had a greater impact on soil fertility, with lower humic N levels than similar rotations without cotton. Interestingly the effect on soil fertility seemed to be accentuated when the main grain crop with the cotton was sorghum.

#### *Presentation of results to farmers*

The most appropriate method for presenting these results to farmers was not tested formally because of time factors and the small numbers of farmers involved with the study. However, box and whisker plots (with some initial explanation to farmers who are unfamiliar with them) appear to have merit. They appear to provide key information for decision making in a simple format. Cumulative distribution functions were familiar to the Jimbour farmers group, but began to become difficult to distinguish when five rotations were included at once. Anecdotal evidence would suggest that CDFs would not be simple for many farmers to interpret. Probability functions are suitable for single rotations but incomprehensible for five rotations.

Stochastic dominance measures were not useful in discriminating between the rotations tested here. In addition, as a quick glance at Table 3 might indicate, presentation of the results is an issue. Presentation of the results in mean-standard deviation space is a possibility but was not tested with the farmers.

#### **Conclusions**

Combining price simulation results from @Risk with APSIM results using historical climatic data to generate rotational gross margins may provide a suitable method for generating useful information for farmers making strategic decisions about long-term rotations. The results of this study with farmers on the Jimbour Plains of Queensland indicates presenting the output as box and whisker plots to illustrate variations in profitability might also be suitable although this requires further investigation.

The evidence from this study adds weight to the suggestions by other researchers that lucerne can help reduce drainage from the profile, but may not be economic under current conditions. Cotton rotations in this area of Queensland are more profitable than other rotations, but are also more risky and could lead to declines in soil fertility and increases in drainage.

#### **Biographical Sketch**

Roy is Senior Lecturer in Farm Management and Agricultural Extension at the Muresk Institute, Curtin University of Technology in Western Australia. Apart from WA he has worked in NSW, USA, and the South Pacific (lecturing in agricultural extension) and Tasmania (as an extension officer). Roy has more recently been involved in projects in South Africa and the Philippines as well as WA and Qld. His research interests are in the application of soft and hard systems approaches to issues of decision making, adoption and rural development and it is the interest in this latter issue that led to his work on collaborative groups and cooperatives. His undergraduate training was in Rural Science (UNE) with postgraduate training in Agricultural Economics (Cornell - MSc; UNE - PhD) and a Grad Dip in Agricultural Extension from Melbourne.

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