Combining biophysical and price simulations to assess the economics of long-term crop rotations

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Abstract

Long-run rotational gross margins were calculated with yields derived from biophysical simulations in APSIM over a period of 100+ years and prices simulated in @Risk based on subjective triangular price distributions elicited from the Jimbour Plains farmer group. Rotations included chickpeas, cotton, lucerne, sorghum, wheat and different lengths of fallow. Output presented to the farmers included mean annual GMs and distributions of GMs with box and whisker plots found to be suitable. Mean-standard deviation and first and second-degree stochastic dominance efficiency measures were also calculated. Including lucerne in the rotations improved some sustainability indicators but reduced profitability.

1. Introduction

An experimental project being conducted with a group of farmers on the Jimbour Plain in Queensland is investigating the effect that lucerne is having on sub-soil permeability, on water infiltration and possible water availability to subsequent crops in addition to the effect of organic carbon on soil surface structure (Dalgliesh & Connolly 1999). Key issues being addressed by the project are the technical issues relating to the effects of lucerne on water availability for subsequent crops and the practicalities of removing the lucerne ley (Dalgliesh et al. 2001). Various rotations incorporating chickpeas, cotton, lucerne, sorghum, wheat and different lengths of fallow are being compared with and without lucerne. The experimental results are being simulated with APSIM; Agricultural Production Systems Simulator (Keating and McCown 2001; Keating et al. 2002) which is a farming systems simulator that combines climate risk analysis with the prediction of long-term consequences of farming practice on the soil resource. This allowed biophysical information on various rotations to be generated using simulations based on historical rainfall and climatic data.

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 considered as well.

An approach based on calculating rotational gross margins derived from simulations in APSIM and @Risk was chosen with the results presented as probability distributions, cumulative probability distributions and box and whisker plots. This produced meaningful results for use by farmers and found that lucerne has some benefits for environmental sustainability but is not economic under the assumptions used.

2. Options for analysing the economics of long-term rotations

A wide range of analytical frameworks can and have been used to analyse the economics of long-term rotations from simple Gross Margins through to complex linear, non-linear and dynamic programming techniques. The choice of technique depends on the purpose and context of the study. Some of the considerations include: scale (paddock through to region), audience (farmers versus researchers versus policy makers), need to incorporate risk (climate, price, pests and diseases), which other factors to include (e.g. sustainability, dynamic), and of course availability of data and expertise.

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. This model was used to simulate crop growth on their site using historical climate records. It incorporates many dynamic crop and soil factors; can handle issues such as variable sowing times and rotations; and outputs yields, protein levels and some sustainability factors. However, it does not simulate pest and disease effects.

2.1 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. When analysing the economics of perennials in the farming system the factors to be considered include short-term profit, dynamic effects, sustainability, risk and whole-farm (Pannell 1995).

Because lucerne is a perennial it involves additional complications. Establishment and removal are expensive which generally means a longer phase in the rotation. However, in the context of this study, because lucerne can dry out the soil profile, growth was generally insignificant after two years (Dalgliesh et al. 2001). Drying out the profile can also have negative consequences for the crop following lucerne, leading to reductions in yield or longer fallow periods Weston et al. 1997, Dalal et al. 1991). Lucerne can also have nitrogen and carbon benefits for following crops (Weston et al. 1997).

Another important 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.

These issues complicate biophysical modelling and economic analysis, but if they are oversimplified the results may be too removed from reality to be relevant to the farmers. In fact one of the issues stressed by the farmer group involved in this project was the need to allow for opportunity cropping and variable sowing times.

2.2 Farmer decision making

The context of this study is that farmers are 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. However, as was made clear by the farmer group involved with the study and as has been found by other researchers (Cary and Wilkinson 1997; Pannell 2001), profitability is an important influence on decisions to adopt change even if there are other ‘sustainability benefits’.

Risk preferences also influence farmers’ decisions. There is strong evidence that Australian farmers are risk averse (Bond and Wonder 1980; Bardsley and Harris 1991; Kingwell 1993; 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. In addition, the level of risk aversion varies from person to person (Bond and Wonder 1980; Munro and Fisher 1982).

There is also evidence that people respond differently in situations of Knightian uncertainty and ambiguity (Camerer and Weber 1992; Sarin & Weber 1993; Kunreuther et al. 1995; Ghosh and Ray 1997; Mukerji 1998; Murray-Prior and Wright 2001). An implication of these findings is that farmers develop strategies to cope with uncertainty (Murray-Prior and Wright 2001) and higher-level strategies set the context for lower-level decisions. 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.

The two main sources of risk and uncertainty in cropping are yield variation (largely a function of climate variation) and price variation (a function of supply and demand variation). Variability in profitability of a rotation is consequently a function of both these variables.

2.3 Presenting information to farmers

Since the purpose of this study was to provide information that could be used in a discussion with farmers, it needed to take account of the evidence that farmers are risk and uncertainty averse, that responses to these will vary by person and depend on the context of the decision. Consequently 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.

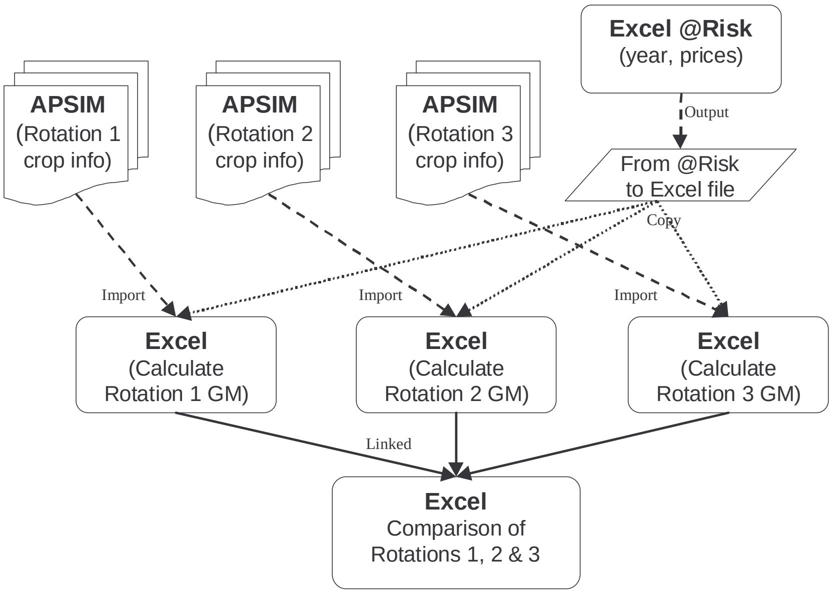
2.4 Choice of analysis method

Given the purpose and context of the study it was decided to compare long-run rotational gross margins for the various rotations. Yields (and other physical outputs) were simulated using APSIM over a period of 100+ years and prices were simulated in @Risk (see method section for details). This approach allowed detailed modelling of most of the factors (short-term profit, dynamic, sustainability and risk) affecting legume production outlined by Pannell (1995). Whole-farm factors were not explicitly incorporated in the model but were explicitly and explicitly considered in discussions with the farmers and implicitly in the choice of rotations and estimated costs of machinery hire.

3. Method

The analysis was conducted in four steps: Simulating biophysical data in APSIM, simulating prices in @Risk, combing 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



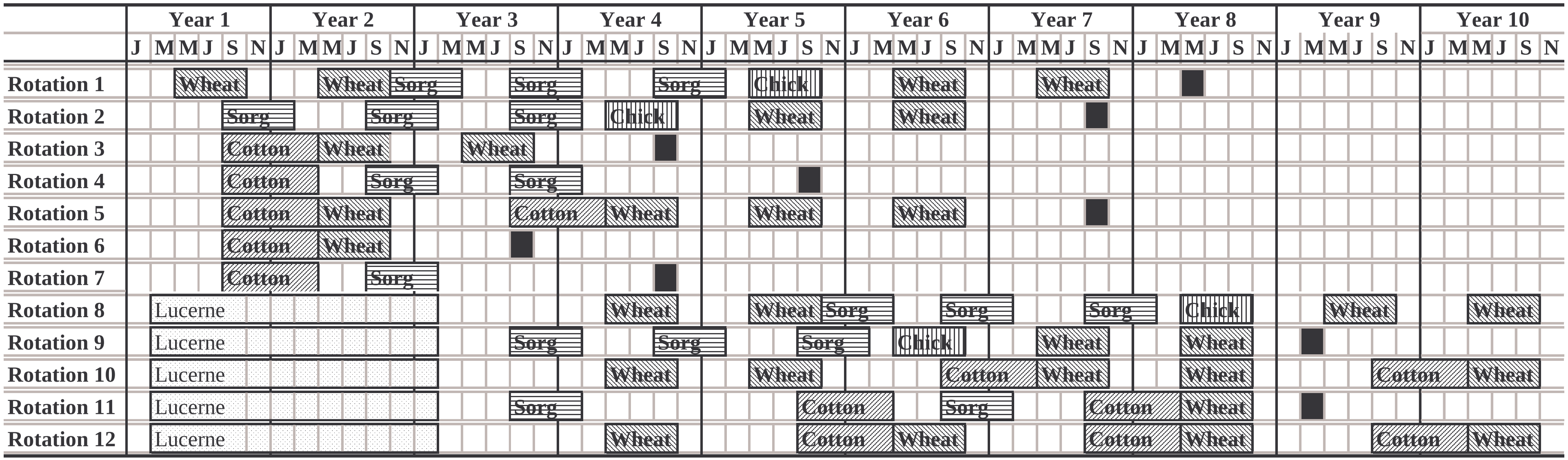
3.1 Validation of the APSIM model

In order to develop confidence in the model the results from the 5-year rotation trial described by Dalgliesh et al. (2001) were simulated and the results presented to the collaborating farmers and agribusiness consultants. Each of the different rotational sequences described by Dalgliesh et al. (2001) were simulated for two soil types.

3.2 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
Rotation 2: Sorghum-chickpea
Rotation 3: Cotton-wheat
Rotation 4: Cotton-sorghum
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

3.3 Biophysical modelling of rotations in APSIM

APSIM was initiated using the starting parameters in Table 2. 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. Two types of simulation were preformed a must sow where each crop was forced to be sown at the end of the sowing window if the sowing rules had not been met; and a variable simulation where crops were only sown when the sowing rules had been met. The variable rotations required some must sow rules to maintain the rotational sequence and maintaining the offset arrangement of the rotations in the different paddocks. Sowing rules and parameters for each crop are presented in Table 3.

Table 2: Initial starting parameters for simulations

Site	Jimbour
Soil	Grant soil ref#16
Starting crop	Lucerne
Sowing Rules	1 Apr – 15 June when 100 mm of water in the top 60 cm of soil
% Water	100%
PAWC (lucerne)	537 mm
Starting Nitrogen	216 kg/ha
Cultivar	Trifecta
Sowing depth	40 mm
Density	350 plants/m^2
Meteorological data	Dalby Qld 1890-2000
Simulation type	Continuous rotation

3.4 Economic modelling

In step two, price variability was estimated by the farmer group using triangular distributions of long-run prices for the various crops. Implicit in this are the assumptions that future prices will reflect the farmers' expectations of these prices and that these are the appropriate prices to use in comparing the rotations rather than historical prices. A similar distribution was also obtained for urea as this is a major input and its price is highly variable (see Table 4). These were farm-gate prices. Consideration was given to using an historical prices series and incorporating covariance of yields and prices in the simulation but a suitable price series was not available. Since most of these crops are exported this is unlikely to be a major weakness although there is an argument that sorghum and lucerne could be exceptions to this. Price distributions for the crops and urea were simulated in @Risk (ver. 4.0) for 1000 iterations using the Latin Hypercube method (Palisade 1997).

Table 3: Parameters and sowing rules for the cropping sequence within each rotation

Crop	Lucerne	Cotton	Sorghum-LF	Sorghum-SF	Wheat	Wheat-NF	Chickpea
Sowing window	1-Apr 15-Jun	1-Oct 15-Nov	15-Nov 15-Jan	15-Sep 15-Jan	15-Jun 7-Jul	15-Jun 7-Jul	15-Jun 7-Jul
Sowing water	25 mm of rain over the last 7 weeks and 100mm in top 60cm	50 mm of rain over the last 7 weeks and 200 mm in top 150 cm	25 mm of rain over the last 7 weeks and 100 mm in top 120 cm	50 mm of rain over the last 7 weeks and 100 mm in top 120 cm	50 mm of rain over the last 7 weeks and 100 mm in top 120 cm	50 mm of rain over the last 7 weeks and 100 mm in top 120 cm	50 mm of rain over the last 7 weeks and 100 mm in top 120 cm
Rules if conditions not met	Must sow	Sow Sorghum-LF	Fallow	Fallow	Fallow	Fallow	Fallow
PAWC (mm)	537	322	273	273	317	317	161
Density	350	12	7	7	100	100	25
Row spacing (cm)	50	150	100	100	25	25	750
Depth (mm)	40	50	30	30	30	30	40
Minimum Nitrogen (kg/ha)	-	200	200	250	250	-	-
Cultivar	Trifecta	Siok	Medium	Medium	Hartog	Hartog	Amethyst

*Wheat-NF always followed Sorghum-LF (NF= No Fertiliser, LF= Long fallow, SF=Short Fallow)

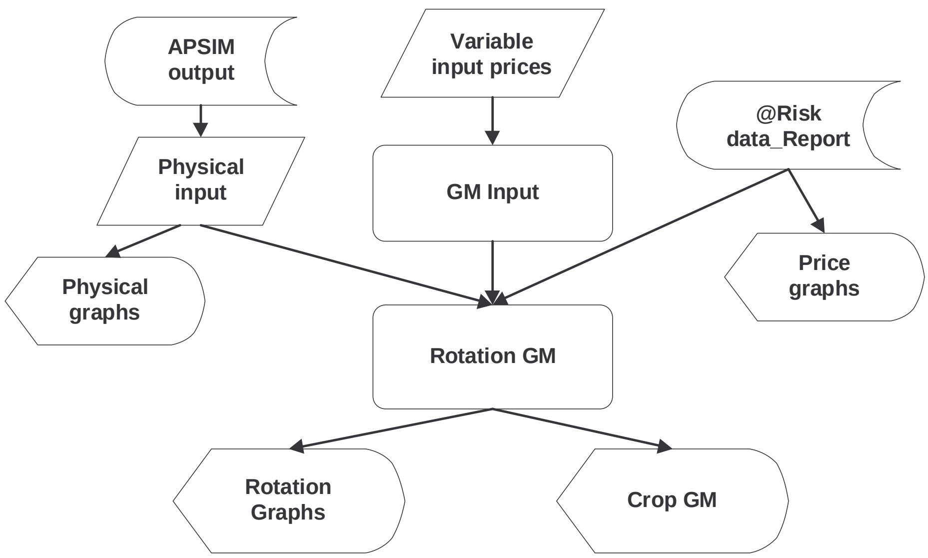
Table 4: Prices used in triangular distributions of crops and urea

Crop	Unit	Min	Most likely	Max	Expected
Barley	t	$85	$150	$200	$145
Chickpea	t	$180	$300	$600	$360
Cotton	bale	$280	$480	$620	$460
Lucerne	t	$140	$165	$200	$168
Mungbean	t	$300	$500	$650	$483
Sorghum	t	$90	$140	$220	$150
Wheat	t	$110	$160	$240	$170
Urea	t	$275	$330	$450	$352

An additional issue was how to combine the APSIM results and yield variation with the @Risk simulations. The method chosen 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 (see Figure 2). 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.

Figure 2: Representation of rotational GM calculations



Gross margins were calculated as Gross Income (Yield*Price) minus Variable Costs. Variable costs included Fertilisers, Herbicides, Insecticides, Fungicides and Cropping Operations, with the quantities obtained from discussions with the farmer's group. The chemical prices used were for 2001 and were obtained for commercial quantities from the farmer's input supplier. The costs of cropping operations were imputed from the contract rates reported by the farmer's group. Ownership of equipment varies and this allowed all crops to be compared on an equivalent basis. Some costs were independent of year and yield and others were dependent upon other factors such as paddock history (N use), yield (e.g. lucerne baling) and cuts (e.g. lucerne mowing). Price for wheat was adjusted for protein using a straight-line formula that estimated the Australian Wheat Board adjustments for protein in the range of protein levels simulated.

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).

3.5 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.

3.6 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 shown in Table 5. 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 ≥, and the discrete equivalent of the area under its cumulative distribution function smaller.

4. Results

The main purpose of this paper is to outline a method for analysing the output from crop simulations of long-term rotations that allows farmers and agribusiness professionals to assess the profitability, variation in profitability and other sustainability indicators relevant to their selection of appropriate rotations. Hence 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.

4.1 Validation of Simulations

The results from each of the observed trial rotations were simulated using APSIM and the observed and predicted results were presented to the farmers. At the completion of this the farmers were happy that APSIM could accurately predict their crop yield within a 10% error.

4.2 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 5). 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.

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. This is also apparent from the considerably higher maximum and lower minimum gross margins for these rotations.

Table 5: Rotational gross margin results

	Rotation											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean	402	415	721	628	731	805	649	302	299	490	527	593
Median	393	430	742	616	733	767	643	291	292	479	523	586
SD	329	255	569	335	559	650	372	255	256	339	338	545
Min	-356	-332	-723	-455	-723	-869	-490	-266	-268	-303	-445	-572
5%	-60	-34	-372	134	-382	-478	106	-65	-114	-34	-64	-354
10%	-6	85	-68	245	41	96	205	-22	-24	60	59	-121
15%	41	168	218	331	220	260	303	31	17	127	194	30
20%	86	208	317	384	333	352	351	64	58	201	279	141
25%	123	249	418	423	425	429	402	92	107	250	335	228
30%	185	283	492	462	493	499	448	129	139	296	382	287
35%	232	324	558	502	554	567	502	168	173	355	421	354
40%	296	359	615	540	604	627	550	211	212	394	457	432
45%	345	400	679	575	670	698	597	254	248	439	493	514
50%	393	430	742	616	733	767	643	291	292	479	523	586
55%	443	467	809	652	798	819	676	334	335	515	572	671
60%	489	492	857	686	847	907	732	379	372	562	613	747
65%	539	520	927	743	916	982	775	415	421	602	649	829
70%	585	561	998	790	986	1,078	832	447	459	651	695	896
75%	642	590	1,091	841	1,081	1,187	898	497	505	701	735	978
80%	700	633	1,192	897	1,166	1,312	956	545	552	787	788	1,074
85%	770	693	1,296	975	1,282	1,491	1,031	591	605	838	840	1,175
90%	849	737	1,434	1,070	1,442	1,661	1,120	648	649	968	961	1,310
95%	957	816	1,631	1,189	1,640	1,872	1,285	738	707	1,094	1,098	1,469
Max	1,325	1,087	2,257	1,636	2,546	3,262	1,862	962	832	1,445	1,480	2,250
Skewness	0.16	-0.34	-0.30	-0.21	-0.10	0.05	-0.03	0.13	-0.02	0.16	-0.13	0.01
Kurtosis	-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 2: Sorghum-chickpea
Rotation 3: Cotton-wheat
Rotation 4: Cotton-sorghum
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

4.3 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 3; Figure 4). In all cases except for the cotton-sorghum rotations the lucerne also decreased the downside risk as measured by the minimum gross margin.

Figure 3: Boxplot of grain rotations with and without lucerne

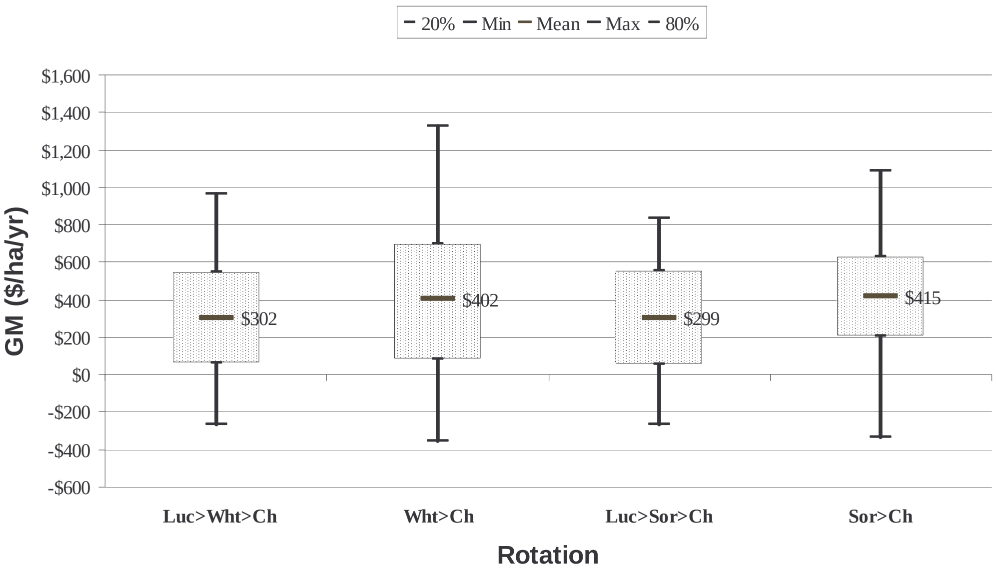
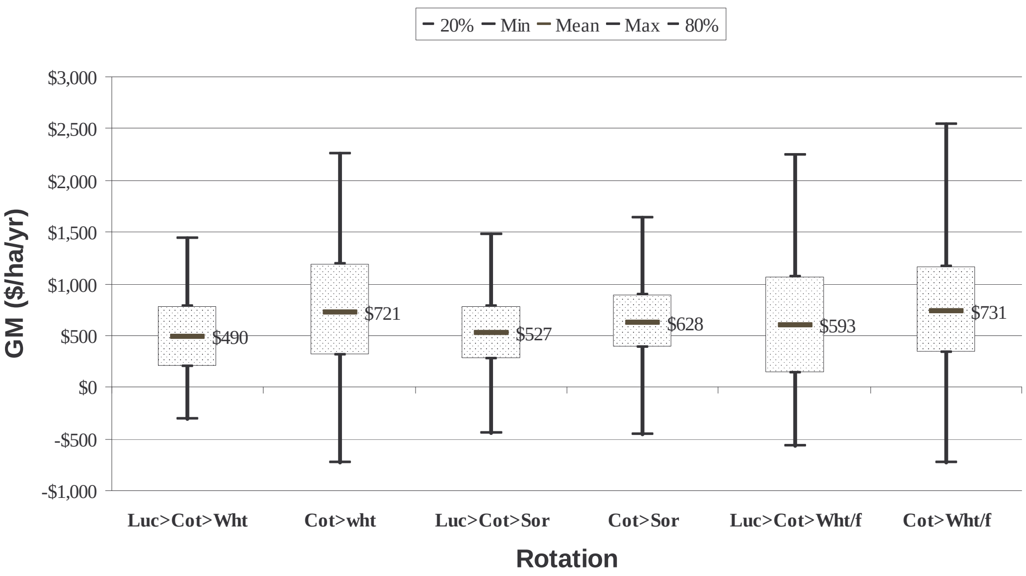


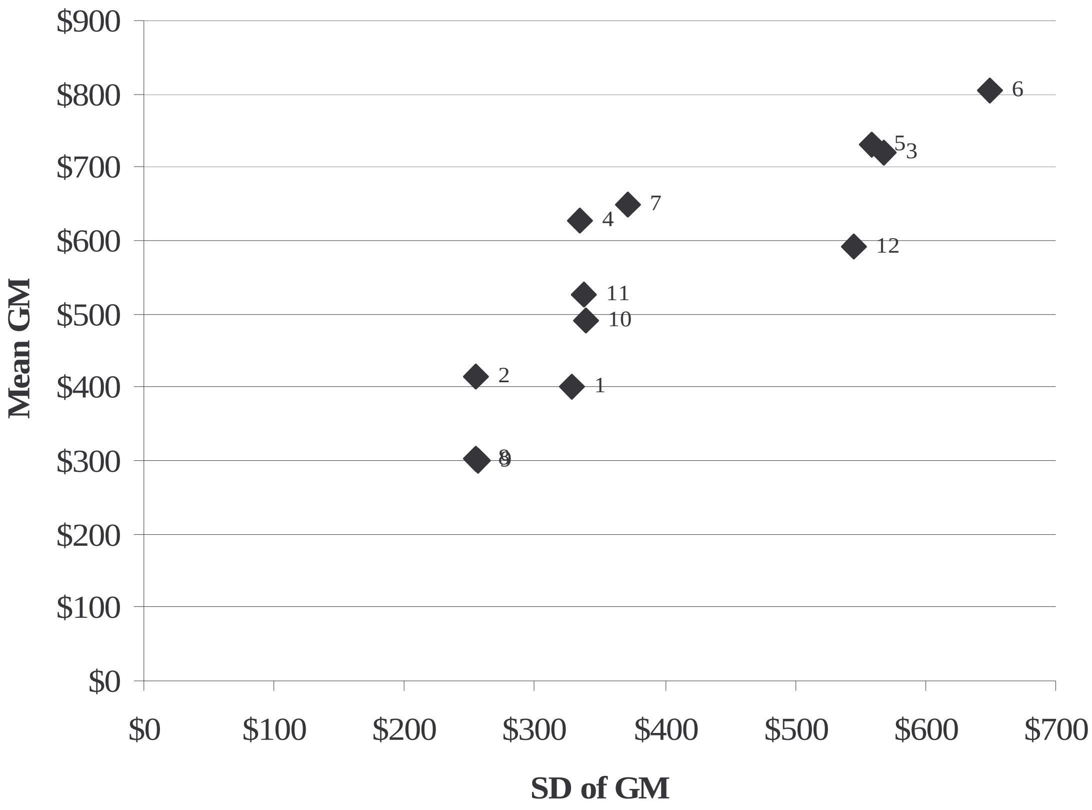
Figure 4: Boxplot of cotton rotations with and without lucerne



4.4 Riskiness of rotations

In general, the higher the mean gross margin, the higher the dispersion of gross margins (Table 5). This can be represented in mean-standard deviation space (Figure 5) 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 5: Rotations[a] in mean-standard deviation space



[a] Numbers correspond to rotation numbers in Tables 1 & 3.

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 6. 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 6: Pair-wise comparison matrix[a] showing results of second degree stochastic dominance analysis[b] of rotations

	Rotation[c]											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	*	-	?	?	?	?	?	?	?	-	?	?
2	+	*	?	?	?	?	?	?	?	-	?	?
3	?	?	*	?	?	?	?	?	?	?	?	?
4	?	?	?	*	?	?	?	?	?	?	?	+
5	?	?	?	?	*	?	?	?	?	?	?	?
6	?	?	?	?	?	*	?	?	?	?	?	?
7	?	?	?	?	?	?	*	?	?	?	?	+
8	?	?	?	?	?	?	?	*	+	?	?	?
9	?	?	?	?	?	?	?	-	*	?	?	?
10	+	+	?	?	?	?	?	?	?	*	?	?
11	?	?	?	?	?	?	?	?	?	?	*	?
12	?	?	?	-	?	?	-	?	?	?	?	*

[a] + = Rotation in row dominates column; - = Rotation in row is dominated by column; ? = Rotation in row neither dominates nor is dominated by column.

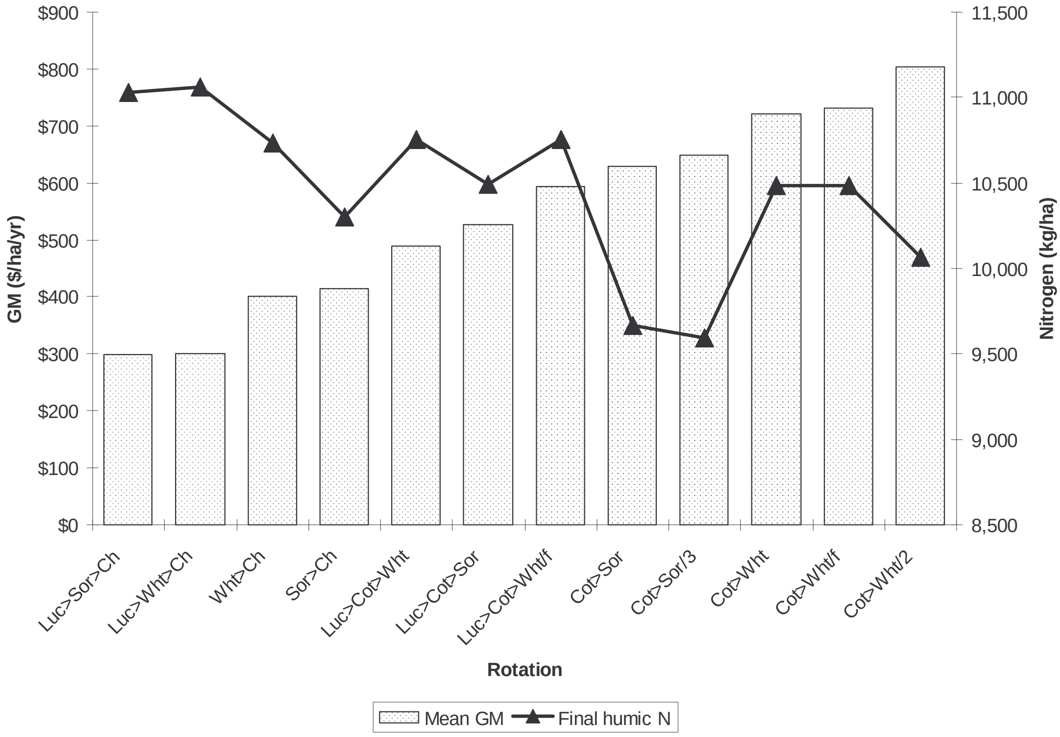
[b] Analysis based on discrete method using fractile values in Table 5.

[c] Numbers correspond to rotation numbers in Tables 1 & 3.

4.5 Environmental sustainability comparisons

An inverse relationship was found between mean gross margin and final humic N (Figure 6). 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.

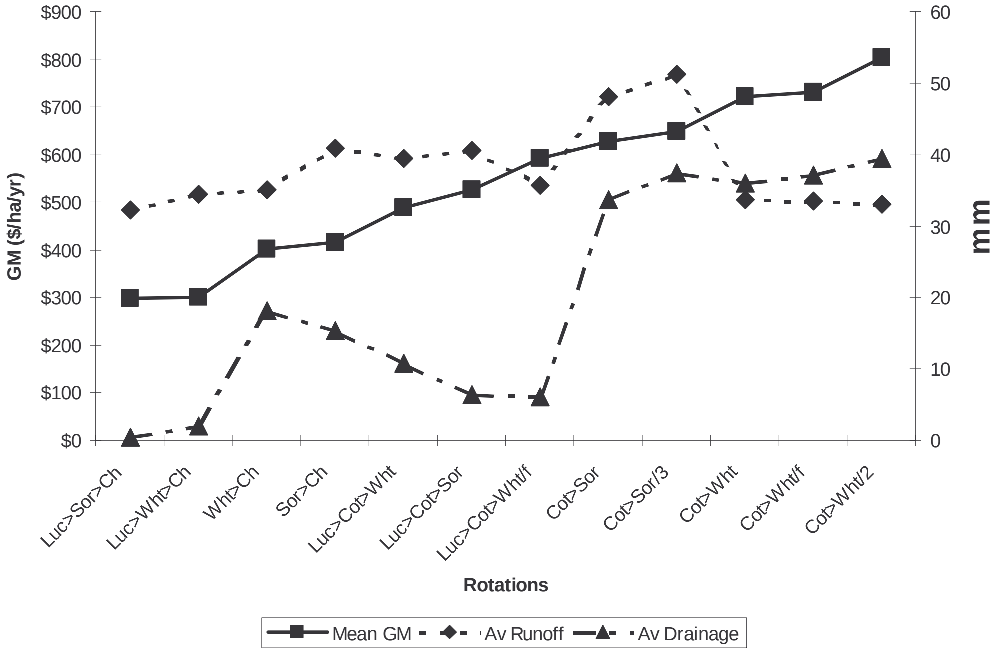
Figure 6: Mean gross margins of rotations versus final humic N



A similar result was found for drainage, as the rotations with higher mean gross margins tended to have higher average drainage levels (Figure 7). 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.

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.

Figure 7: Mean gross margins of rotations versus average runoff and drainage



5. 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.

5.1 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. This is an advantage over linear programming approaches. Although the results are not presented here it also can be used to analyse variable or opportunity rotations, although there were some issues and problems with the biophysical simulation of these rotations. An additional advantage is that the results can be easily and quickly presented in a variety of formats for farmers and others. The riskiness of the results can be presented graphically or as the results of efficiency analysis.

Unfortunately yield and price covariance, which can also affect the results and which is a factor that may affect decisions (Pannell 1995) was not included in this analysis although it is possible to do so given relevant data. Even if price and yield series were available a key question would be how to establish the appropriate covariance measures. One method might be to establish the relationship between the rainfall used in the simulation model, which is a key driver of yield, and prices for the commodities over the length of the series.

Another weakness of the methodology is its 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. Because it does not take account of labour, machinery and financial constraints, for instance, these factors also need to be considered by the decision maker in selecting the optimal rotation.

5.2 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. This supports Bathgate and Pannell (2002) who suggest that farmers are unlikely to incorporate it in their rotations unless its performance improves. Key reasons for this are the high costs of establishment and removal, and also that in most periods it dries out the profile after two years and is not productive after that. 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. It was initially hypothesised in the research that the addition of lucerne to a rotation might benefit following crops by improving soil structure so that the amount of water available would be increased. Since there are no research results support this as yet, it was not included in this modelling scenario.

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.

From a public policy perspective, lucerne might be more easily incorporated in a cropping program than trees to decrease drainage and consequently reduce water table and salinity problems. However, because it reduces profitability, farmers would need to be compensated to induce them to include it in their rotations. While farmers will take other factors into consideration in their decisions, under the assumptions of this model, at least $100 per hectare would be required for farmers to break even. Of course a large increase in lucerne production may have a negative impact on price because much of it is sold for domestic consumption and consequently would increase the level of compensation required.

5.3 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 OK for single rotations but incomprehensible for five rotations. As Meinke et al. (2001) suggest all these methods require farmers to have some understanding of probability, which could be a constraining factor. The appropriate method to present these results requires further investigation.

Stochastic dominance measures were not particularly useful in discriminating between the rotations tested here. In addition as a quick glance at Table 6 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.

5.4 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.

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