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A SIMPLE PROCEDURE FOR THE EVALUATION OF CROP RESEARCH PROPOSALS

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INTRODUCTION

The Grains Research and Development Corporation requires applicants for research funds to show "how the likely results will ultimately impact in scientific and economic terms on the industry and how they will be of national benefit". Applicants are asked to assess the adoption of findings "over time and space" and to consider the "commercialisation and/or patenting of project results".

The development of basic evaluation procedures by Agricultural Economists in the past has allowed economists working with scientists to respond to this new emphasis research funding bodies are placing on the economic evaluation of research proposals. The number of papers at this conference, addressing the evaluation of research proposals shows that this subject is an ongoing concern of many Agricultural Economists.

This paper describes a simple evaluative procedure that scientists can use to measure the relative profitability of crop research proposals. The procedure uses data that are available and procedures of economic evaluation that are generally accepted. A spreadsheet (Smart or Lotus) is used to process the data.

The procedure was developed to evaluate 20 research proposals that emerged from a meeting of 40-50 scientists, extension officers and producers interested in six grain legume crops able to be grown in central Queensland. It has had good acceptance by scientists who have used it or who have studied its results, and research managers have recognised the advantage of having research proposals subjected to an economic evaluation.

THE PROCEDURE

The procedure is built around a questionnaire that collects data which is used to construct a cash flow budget for the project. Standard discounting procedures are used to measure the Net Present Value (NPV) and Internal Rate of Return (IRR).

Data Collection

The favoured method of data collection and analysis for individuals and small groups is to work interactively with a computer. The scientist is able to key in his expectations and get an immediate estimate of NPV and IRR. He can key in changed expectations to test their effect on the outcome. He can continue to make changes until he has a good understanding of the project and a final estimate of profitability.

When working with 3 or more scientists it is easier to work with a questionnaire with follow-up sessions to discuss results and amendments.

Scientists provide information in the following general areas:

1. The present gross margin of the subject crop;
2. The expected yield gain (best, most likely and worst) and level of achievemnt each year;
3. The expected price gain (best, most likely and worst) and the level of achievement each year;
4. Changes to costs and level of achievement each year;
5. Current area of subject crop
6. The percentage of current area to benefit each year;
7. Changes to crop area due to research;
8. The average gross margin of displaced crops;
9. Expected cost of research and extension each year;
10. Additional outlays on farms each year; and
11. The interest rate to be used to calculate the NPV.

The spreadsheet used for data collection, processing and reporting is shown in Appendix I.

The time required to collect data and complete an evaluation is 20-40 minutes. This time would usually be sufficient to allow an examination of a range of possible outcomes.

Uncertainty

Allowance for uncertainty of research outcome is made in the estimates of change in yield and crop price. The beta distribution technique is used to estimate the average yield and price changes from estimates of the best (b), most likely (m) and worst (w) outcomes (Metwally *et al.* 1981).

Sensitivity Analysis

Sensitivity analysis can be used to test the response of a projects profitability to different outcomes. This is done by changing, one at a time, assumptions of prices, yields, costs, rates of achievement, crop area, life of benefits etc. An optional project file that performs a sensitivity analysis is attached to the spreadsheet.

Output

The output lists the assumptions, reports the gains made from the current area and the expanded area and concludes with the estimates of NPV and IRR. A series of sensitivity tables showing the effect of more/less optimistic outcomes is an option.

ADVANTAGES

The procedure requires minimal time to collect and process data. The spreadsheet is "transparent" (i.e. it is made up of relatively simple formula except for the calculation of NPV and IRR) and easy to explain. Scientists exposed to it have accepted it and find it easy to use.

Use of the procedure will make scientists more sensitive to those factors that contribute to the profitability of research projects. Sensitivity analysis will show them the value of getting their research results adopted quickly - they will be encouraged to place more emphasis on collecting data that is easier to commercially evaluate and apply and they will take a greater interest in assuring their results are promoted through the extension system.

The simplicity and speed of the procedure will encourage scientists to explore a wider range of research options in search of proposals that have higher rates of return and that will appeal to funding bodies.

Scientists and rural research agencies seeking to sell plant variety rights, licence agreements, patents, or some other right to a research result can use the procedure to explore the market value of the product. The price negotiated for the technology will depend on the extent to which benefits of research can be restricted to those who purchase the rights, after allowing for a reasonable return to end users.

One of the most important benefits is the realisation by agricultural research staff in the public service that the work they do has a high value to farmers and the general community. It is reasonable to expect an increase in confidence, self esteem and performance as a consequence.

LIMITATIONS

The limitations of this procedure are similar to those of a $150 accounting software package compared with a $1000 package. To maintain its simplicity and ease of explanation has required a number of compromises.

An important limitation is the inability of the procedure to measure the "riskiness" of the proposals as indicated by a measure of the standard deviation of the NPV and IRR associated with the range of price and yield nominated by scientists. The addition of an optional monte carlo simulation procedure which will allow comparisons of the probability distributions of internal rates of returns of different proposals (Van Horne 1968) is being considered.

The spreadsheet can handle only simple situations. New crop combinations, changes in rotations, increased cropping intensity etc would be quantified in supporting worksheets and the data transfered to the evaluation worksheet.

Evaluations are usually done on a marginal basis where only costs such as salaries of scientists and assistants, the operating and capital costs of the project are considered. The cost of providing vehicles, laboratories, administration and professional support, supervision etc are excluded from the evaluations. As a result some IRR's are very high (200% +) and need to be interpreted cautiously.

The NPV and IRR measures are very sensitive to changes in area, yield, price and costs and rates of achievement. This leads to the suggestion that figures can be derived to support almost any judgement of a particular research activity (Harvey 1988).

A counter to this possibility is the requirement that scientists expose there expectations as listed on the spreadsheet to challenge and debate throughout the research project selection and funding process.

The generation of unambiguous, easily compared NPV and IRR figures may be interpreted by some as removing the need for scientists to be as involved in the decision making process as in the past. This is not the case. There will be an ongoing need for all who are involved in the research system to continue to be involved in the decision making process (Harvey 1988)

It is difficult to verify evaluations of research proposals after the project has been completed and the results implemented. This is because the benefits of research are shared by farmers, consumers and the general community. The competitiveness of the rural sector in Australia and competing countries (many small producers selling a homogenous product) and the transferability of research means that many of the benefits due to rural research in Australia ultimately go to consumers as lower prices, better quality and a bigger range of products (Harris and Lloyd 1990, Lloyd *et al.* 1990).

The failure to confine benefits to immediate/recognised clients may lead scientists to believe their research has failed even though they may have achieved their initial goals.

Gaining Acceptance

Before economists expect scientists to accept alien concepts such as profitability, discounting, monte carlo simulation etc. they have to be clear about the benefits they are offering. What is being offered is knowledge and techniques that will help them select and design better projects; that will improve their ability to attract funds; that will give them an appreciation of their value to their clients and community thereby building their confidence and esteem; that will help them defend themselves against the razor gangs seeking to cut research funding; that will help them make the decisions that have to be made concerning the allocation of limited research resources.

It will also help if the evaluative procedures are seen to strengthen the traditional decision making process of individual scientist and scientific groups.

This can be achieved so long as agricultural economists are seen to be a part of the "research team" and not seen to be sitting on the sidelines passing judgement. We need to keep everything reasonably simple and explainable and not demand too much of time.

CONCLUSION

The spreadsheet used for the evaluation records the assumptions which form the basis of the evaluations. This listing of assumptions helps guard against flagrant abuse.

The sensitivity analysis project file provides users with a indication of the sensitivity of results to changes in assumptions. The lack of a standard deviation measure of the outcome is a lack that has to be corrected.

The suggestion that figures can be derived to support almost any judgement of a particular research activity is accepted. The availability of seemingly unambiguous figures (NPV and IRR) is not seen to be a substitute for the judgements that have to be made by scientists involved in the decision making process. It is expected that decisions made by scientists will be improved by the additional information provided by the technique.

Finally, it is vital that the scientists involved have a proprietal interest in the outcome of the evaluations so that they do not ignore the results generated from the data they provide.

REFERENCES

Grains Research and Development Corporation (1991), *Explanatory notes relating to applications for grants from Grains Research and Development Corporation for 1991-92.*

Harris, M. and Lloyd, A. (1990), *The Returns to Agricultural Research and the Underinvestment hypothesis - a survey*, Australian Agricultural Economics Society Annual Conference, Brisbane, February 1990.

Harvey, D.R. (1988), Research priorities in agriculture, *Journal of Agricultural Economics* Vol 39.

Lloyd, A., Harris, M. and Tribe, D. (1990), *Australian Agricultural Research: Some Policy Issues*, The Crawford fund for International Agricultural Research, 1 Leonard Street, Parkville Vic 3052.

Metwally, M.M., Tamaschke, H.U. and West, G.R. (1981), *Operations Research - Theory and Applications to Business Economics*, (J.K. Publishers: London).

Van Horne, J.C. (1968), *Financial Management and Policy*, (Prentice-Hall Inc., Englewood Cliffs, New Jersey.

APPENDIX I
SPREADSHEET FOR ESTIMATING THE PROFITABILITY/VALUE OF CROP RESEARCH PROPOSALS
By J.R. Page, Biloela Research Station.

File name-Ray2

Q1. Date of evaluation: 30/07/90

Q2. Crop/variety that is subject of research: Sorghum

Q3. A brief description of the research proposal: Continuation of program to breed higher yielding, midge resistant soghum

Q4.	What is the current average yield?	1.575 t/ha	
Q5.	What is the current average price?	108.00 $/t at farm gate	
Q6.	What is the average total of variable costs?	76.35 $/ha	
	THE CURRENT AVERAGE GROSS MARGIN IS	**93.75 $/ha**	
Q7.	What is the worst yield change expectation?	0.233 t/ha	(Gain: nominated for this project should
Q8.	What is the most likely yield gain expectation?	0.233 t/ha	not include gains due to other research)
Q9.	What is the best yield change expectation?	0.233 t/ha	
	THE AVERAGE EXPECTED YIELD CHANGE IS:	**0.233 t/ha**	(= 100% of expected yield ch[illegible])

Q10. Nominate the percentage of yield change achieved in each year (entered as a decimal i.e. 0.1 = 10%, up to 100%)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%

Q11.	What is the worst price gain expectation?	0.00 $/t	(Due to quality change, lower cartage,
Q12.	What is the most likely price gain outcome?	0.00 $/t	cleaning, drying, etc. costs)
Q13.	What is your optimistic price gain expectation?	0.00 $/t	
	THE AVERAGE EXPECTED PRICE GAIN IS:	**0.00 $/t**	(= 100% of expected price change)

Q14. Nominate the percentage of price change achieved each year (enter as a decimal i.e. 0.1 = 10%up to 100% of expected)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Q15.	By how much will this project change seed costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q16.	fertiliser costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q17.	herbicide costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q18.	insect control/scouting costs?	-5.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q19.	fungicide costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q20.	defoliant costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q21.	irrigation costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q22.	aerial spraying costs?	-3.65 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q23.	harvesting costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q24.	cartage costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
Q25.	drying/cleaning/storage costs?	0.00 $/t	increase (considered in price calculations)
Q26.	machinery costs?	0.00 $/ha	(-'ve for cost decrease, +'ve for cost increase)
	THE EXPECTED CHANGE IN VARIABLE COSTS IS:	**-8.65 $/ha**	(= 100% of expected variable cost change)

Q27. Nominate the percentage of variable cost change achieved each year. (Enter as a decimal e.g. 0.1 = 10%, up to 100%)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%

THE GAIN IN GM/HA EACH YEAR ON THE ESTABLISHED AREA IS ($/ha):

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
3.38	6.76	10.14	13.52	16.90	20.28	27.04	30.42	33.81	33.81	33.81	33.81	33.81

Q28. What is the current area of the crop? 214 000 ha

Q29. What percentage of the current crop area will benefit from this proposal?
(Enter as a decimal, it will be displayed as a %, e.g. 0.1 = 10%, up to 100%)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
5%	10%	15	20%	25%	30%	35%	40%	45%	50%	50%	50%	50%

THE GAIN IN TOTAL GROSS MARGIN ON THE ESTABLISHED AREA IS ($):

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
36171	144685	325542	578742	904284	1302169	1772396	2314966	2929879	3617135	3617135	3617135	3617135

Q30. How will the total area planted change as a result of this project (ha)? (Do not include area change not directly due to this research.)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0	0	0	0	0	21.400	21.400	32.100	32.100	42.800	53.500	64.200	64.200

Q31. What is the average gross margin/ha of the crops displaced by the researched crop? 77.00 $/ha

THE GAIN IN TOTAL GROSS MARGIN ON THE EXPANDED AREA IS ($):

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0	0	0	0	0	792506	864849	1405787	1514301	2163754	2704693	3245631	3245631

THE GAIN IN GROSS MARGIN ON THE CURRENT & EXPANDED AREA IS ($):

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0	144685	325542	478742	904284	2094685	2637245	3720754	4444181	5780889	6321828	6862766	6862766

Q32. How much will the research program cost? (include the cost of the scientist, the assistant and their operating and capital costs)

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	0	0

Q33. How much will it cost to train producers in the application of the research findings (the cost of the extension program)?

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0	0	0	0	0	0	0	0	0	0	0	0	0

Q34. How much will producers have to invest to gain the predicted research benefits (total of investment on all farms $/year)?

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
0	0	0	0	0	0	0	0	0	0	0	0	0

THE NET CASH FLOW OF THE PROJECT IS CALCULATED TO BE ($):

Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12
-75000	69685	250542	503742	829284	2019675	2562245	3645754	4369181	5705889	6246828	6862766	6862766

Q35. What interest rate should be used to calculate the Net Present Value? (enter as a decimal) 9.00%

THE NET PRESENT VALUE FOR THIS PROJECT IS: $22,861,326.00

THE INTERNAL RATE OF RETURN OF THE PROJECT IS: 227.59%

FARM LEVEL RESPONSES TO LOWER WOOL PRICES UNDER RISK AVERSION

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Adjusting farm management to changing wool market situations has been a dominant concern of Australian farmers in recent years. In this paper we analyse the impact of risk aversion on sheep management decisions under different wool prices. Available evidence indicates that most Australian farmers are risk averse (Bond and Wonder 1980; Bardsley and Harris 1987). Our aim is to determine how risk aversion and wool price interact to affect: total wool production, the proportion of farm area devoted to pasture, the stocking rate of sheep, the level of supplementary feeding of grain and own-price elasticity of supply (at the farm level).

Supply responses and management adjustments are derived using MUDAS, a whole-farm linear programming model of a representative farm in Western Australia's eastern wheatbelt. MUDAS is derived from the MIDAS model but includes nine season types represented in a discrete stochastic programming (DSP) framework. The objective function in this study is maximisation of expected utility which is modelled after Patten et al. (1988).

The paper proceeds as follows. After a brief description of the farm system, we present a summary of key features of the MUDAS model. This is followed by presentation and discussion of model results and, finally some concluding comments.

The Farm System

Agriculture in Western Australia is largely confined to the south-west corner of the state, an area of approximately 250,000 square kilometres. The dryland farm system modelled is based on Merredin Shire in the eastern wheatbelt where almost all farms have a mix of crop and livestock enterprises. Annual rainfall in the region averages 310 mm, with most rain falling from May to October, followed by a summer drought from December to March. Crops are sown in May to July and harvested in November to December. Average farm size in the region is approximately 2500 hectares, most of which is cleared and arable. Farm operations are highly mechanized and most farms are owner operated with not more than one other permanent laborer. Casual labor is hired for only a few months of the year to assist in main tasks such as seeding, harvesting and shearing.

Livestock consist almost entirely of sheep for wool and meat production. Lambing is in late autumn or early spring and shearing is in spring and autumn. Sheep graze annual pastures during winter and a combination of crop residues and dry annual pastures in summer. The pastures contain volunteer annual grasses and herbs, with annual legumes introduced in some cases. Crops include cereals (wheat, barley, oats and triticale) and the legume crop lupins. Crops and pastures are commonly grown in rotation and a recent trend is toward cereal/lupin rotations on sandy soils.

Soils are highly weathered and infertile, with wheat yields in the Merredin

Shire averaging 1.0 tonnes per hectare. Enterprise selection and management according to soil type is a key part of the farming system. All farms include a mix of soil types with different production parameters and management requirements. Seven broad soil classes can be recognized in the region: acidic sands, good sand plain soils, gravelly sands, duplex soils, medium-heavy soils, heavy non-friable soils and heavy friable soils. Further details of the soils are presented by Chadis and Pannell (1991).

The Discrete Stochastic Programming Model

Cocks (1968) developed Discrete Stochastic Programming (DSP) as a means of using linear programming to analyze multistage stochastic problems in which the optimal activity in one period depends on events in past periods. Rae (1971a, 1971b) extended the model and applied it to a vegetable farm. After Rae's application, there was a period with few agricultural applications of the technique (Lambert 1985) but recently it has been the subject of renewed interest from agricultural economists (e.g. Brown and Drynan 1986; Lambert 1989; Lambert and McCarl 1989; Garoian et al. 1987).

MUDAS (Model of an Uncertain Dryland Agricultural System) is a DSP model developed by the Western Australian Department of Agriculture to describe a typical farm in the eastern wheatbelt of Western Australia. The following brief overview of the model can be supplemented by a more detailed description published by Kingwell et al. (1991).

In this study we use three different objective functions. One maximises expected net returns, calculated as gross cash receipts minus variable production costs, fixed costs, living expenses and the opportunity costs of holding assets other than land. The other two objective functions represent two degrees of risk aversion. Two constant absolute risk aversion utility functions are modelled using a method based on the Utility Efficient Programming technique of Patten et al. (1988). The uncertainty represented is due to seasonal variation. In this paper we do not represent price uncertainty. In all three versions of the model, other goals relating to leisure and soil conservation are represented implicitly as constraints.

The model handles dynamics as a timeless one-year loop, whereby parameters for a given year are based on the assumption that the same strategy was adopted in previous years. Interyear effects on technical parameters are thus dependent on the solution selected for the current year, so that the model finds an optimal "equilibrium" solution. This approach greatly reduces model size and facilitates much greater detail in the biological constraints and tactical adjustments represented while still capturing the essential interyear and intrayear dynamics of the farm system. Within the year there are a number of nodes at which decisions must be made contingent on what has already occurred. There are 12 decision nodes for supplementary feeding of grain and for sheep live weight adjustments and two nodes for enterpise area and sheep agistment decisions. The model includes approximately 1400 activities and 1200 constraints and is solved on 80386 microcomputers using the AESOP algorithm (a purely linear version of MINOS) and MARG (Pannell 1990) for matrix generation and report writing.

A feature of MUDAS is its detailed representation of biological relationships and complex enterprise interdependencies, both beneficial and adverse, that exist in the dryland farming system. For example, the model includes representation of:

- seven distinct soil classes, each with unique input-output relationships and numerous rotation options.
- the depressing effect of cropping on subsequent pasture density and productivity,
- the supply of nitrogen by leguminous crops and pastures to subsequent cereal crops and the yield response to nitrogen of different crops on each soil class,
- the added weed burden in crops attributable to previous pasture,
- the various quantities and qualities of crop residues available for feeding sheep, and the dynamics of their deterioration,
- the use of lupin and cereal grains as sheep feed to supplement pastures and crop residues,
- yield penalties associated with late planting of crops,
- the depressing effect on pasture growth of increases in stocking rate.

MUDAS is derived from MIDAS (Model of an Integrated Dryland Agricultural System), a deterministic linear programming model which has been described in detail by Morrison et al. (1986) and Kingwell (1987) and applied to a wide range of problems (e.g. Kingwell and Pannell 1987; Pannell and Panetta 1986; Ghadim and Pannell 1991). MUDAS represents climatic uncertainty through the inclusion of nine discrete season types. Each of these seasons is represented by a submatrix of comparable detail to the deterministic MIDAS model.

The criteria for classifying seasons arose firstly, from discussions with farmers to identify which seasonal features influence their farm strategies and adjustment decisions and secondly, from detailed examinations of climatic characteristics of actual seasons from 1912 to 1988. This resulted in four criteria being identified: the timing of opening rains, the incidence of summer rain, the type of opening rains received and the level of spring rainfall.

The most important climatic factor influencing farm management decisions is the timing of opening rains. The later a crop is sown the shorter the growing season before rainfall ceases and the sooner it experiences unfavorable growing conditions such as shortening day length and low temperatures. Consequently late-sown crops have a relatively low yield potential and in seasons permitting early sowing, yield potential is high. Seasons in MUDAS are categorized as early, mid or late.

The amount of rainfall in summer and early autumn is also an important influence on crop area adjustment options. These rains provide reserves of stored soil moisture and increase expected crop yields. The incidence of summer rain is defined by an index to be high or low. Two types of opening rains are represented, characterised by the presence or absence of light rainfall before the main opening rains. These early rains are not sufficient to allow sowing on heavier soils but do allow earlier sowing of crops on sandier soils. Spring rainfall is characterised as being high or low. This affects final yields but is not a major influence on decision making as it occurs after most management decisions have been made.

The four criteria allow for 24 (= 3x2x2x2) possible types of season. However applying the criteria to rainfall statistics for Merredin from 1912 to 1988 showed that many of the possible seasons are yet to be observed and some have occurred so infrequently as to warrant their inclusion in closely

related groups. Even where some seasons could be differentiated by these criteria, simulation modeling showed that there was little impact on yield, allowing further grouping of seasons. A final set of nine season types with associated relative frequencies was selected as representative of season variation in the region (Table 1).

TABLE 1
Season Types in MUDAS

Season	Sowing time	Summer rain	Spring rain	Earlier sowing on sandy soils	Season probability	Typical wheat yield (tonnes/ha)
1	early	high	either	no	0.17	1.96
2	early	low	high	no	0.12	1.27
3	early	low	low	no	0.08	0.84
4	mid	high	either	yes	0.05	1.60
5	mid	low	either	yes	0.12	0.81
6	mid	high	either	no	0.13	1.28
7	mid	low	either	no	0.09	0.77
8	late	low	either	yes	0.14	0.61
9	late	low	either	no	0.10	0.57
					Expected yield	1.09

Strategic Activities and Constraints

The strategic section of MUDAS describes management options to be undertaken in all seasons, unless a tactical adjustment in a particular season deems otherwise. The decision variables include the allocation of land to pasture and each crop, the rotational sequence of enterprises on each of the seven soil classes, livestock numbers, flock structure, feed sources and uses, machinery, labor and finance.

There is a set of global constraints which applies to all seasons (such as constraints which maintain a steady-state sheep flock) and a set which is repeated with different parameter values for each season type (such as pasture production parameters in each month for each type of season).

Parameters were obtained from a range of sources, including field trials, biological simulation models, scientific, economic and farming publications and subjective estimates made by appropriate experts. The data were reviewed in lengthy consultations with biological researchers and advisers.

Tactical Activities and Constraints

The short-term adjustment options represented in MUDAS arose out of discussion with farmers and from discussions with various advisors and researchers. The adjustment options represented are different for each season and for each soil type in accordance with the advice of our collaborators. They include changes in: enterprise selection on a soil type, grazing management, sheep live weights, sheep agistment and supplementary feeding of grain. All these options are available as tactical responses to climatic information. There are no options for tactical responses to short term price fluctuations.

Tactical adjustments result in changes in inputs, costs and production in the year in which the adjustment occurs and some also have impacts on parameter values in subsequent years. Subsequent effects reflect the fact that one year's deviation from a rotation has an effect on subsequent soil fertility, weed densities and pasture availability. All adjustment activities are either specific to one season or to a set of seasons if the seasons cannot be distinguished at the time of the decision.

Farmers and advisors considered that alteration of crop area on heavy soils in response to seasonal conditions was highly likely to be beneficial but that such adjustments were rarely, if ever, required on light soils. Hence MUDAS includes crop area adjustments on all soils with a high clay content but only on one of the sandier soils. Area adjustment constraints limit the nature and area of adjustment permissible within a selected rotation. Area adjustment activities are specific to the phase of a rotation on each soil class and change herbicide and pesticide costs, tillage method, nitrogen and ph[illegible] tic fertilizer costs, use depreciation of crop gear, stubble handl[illegible] ts, use of limited seeding plant capacity and penalties incur[illegible] late sowing. All such changes are calculated exogenously in spread[illegible] and are represented in the model as net effects (Kingwell et al. 1991).

A large set of livestock adjustments in MUDAS involves agistment (i.e. temporary removal of some sheep from the farm and their placement, at a cost, on pastures or dry feed elsewhere). Agistment is often practiced in periods of prolonged feed scarcity. In MUDAS, sheep other than lambs, rams and breeding ewes can be agisted. Potential agistment periods are June to August and September to April. Each agistment activity is represented as a saving in feed requirement during the agistment, allowing a reduction in stocking rate. Costs of agistment vary according to demand and supply conditions considered likely in different periods of different types of season.

Live weight pattern deviations, which give the farmer the option to allow sheep to gain or lose weight depending on seasonal conditions, affect feed transfer rows (due to changes to energy requirements and intake capacities), finance (due to changes in wool production per head) and sheep numbers (due to changes in lamb production per ewe). MUDAS includes activities for supplementary feeding of grain in each month of each season.

Runs for this Study

A constant absolute risk aversion utility function is modelled. Optimal solutions are derived for two different degrees of risk aversion: 1.0 x 10^{-5} (referred to below as "low") and 2.0 x 10^{-5} (referred to as "high"). These are compared with an optimal risk neutral solution. Changes in key variables between the solutions are recorded. The probability distributions of cash surplus across seasons are calculated. The initial results are for on-farm prices of A$125 per tonne of wheat, A$145 per tonne of lupins and A$2.90 per kilogram of greasy wool. Subsequently we test the sensitivity of results to a range of wool prices.

Results and Discussion

In the first part of this section, results are for a wool price of 290c per greasy kg, net of all selling and transport costs. This price is based on a floor price of 700c/kg, a 30% wool tax and various parameter values (such as average wool cut, transport costs) appropriate for Merredin.

Table 2 shows the impact of risk aversion on major farm variables. It includes some surprising results. Our expectations prior to conducting this study were that risk aversion would tend to increase the area devoted to sheep production at the expense of cropping. This expectation was based on the relative stability of wool production per sheep in different seasons compared to grain production per hectare. In fact the model selects a lower area of pasture under risk aversion. This appears to be due to the much greater cost of production of wool in poor seasons due to the need for supplementary grain feeding and/or agistment of sheep off the property. This greater variability of costs outweighs the greater stability of gross returns in its impact on the variability of net returns. One factor which might change, or at least moderate, this result would be the inclusion of price risk in the model since apart from recent times, wool prices have been less variable than grain prices, which would lead to a preference for wool production under risk aversion.

TABLE 2
Expected Values of Key Farm Variables

	Risk aversion		
	Nil	Low	High
Area devoted to pasture (%)	36	34	31
Sheep numbers (d.s.e.*)	1539	1586	1539
Stocking rate (d.s.e.*/ha)	1.77	2.03	1.87
Wool sold (kg)	7510	7780	7530
Grain storage capacity (tonne)	7	108	84

*dry sheep equivalent.

The other surprising result is that stocking rate is greater under risk aversion. We expected that the higher cost of maintaining sheep in poor seasons would tend to lead to reduced stocking rates under risk aversion. This has been the result obtained in previous studies of stocking rate under risk aversion (e.g. McArthur and Dillon 1971) and seems intuitively correct. If the farmer had to purchase all grain required to maintain sheep in poor seasons, this would indeed be the result. However in addition to higher stocking rates under risk aversion, the MUDAS model selects higher levels of grain storage capacity. This means that the model is able to store grain produced in average and good years to be fed to sheep in poor seasons. Higher stocking rates mean higher gross receipts in poor years, and the cost of this extra production is mainly borne in good seasons through foregone grain sales. Grain storage is effectively a mechanism for transferring income from good seasons to poor seasons, resulting in greater stability of income. McArthur and Dillon (1971) did not account for inter-year grain transfers in their simple model. Casual support for the result is provided by the high levels of grain storage capacity observed on many farms in the Merredin region.

The result of higher stocking rates is consistent under different wool prices (Table 3). At most prices, the stocking rate is highest in the solution for high risk aversion. The result for a wool price of 290c, where stocking rate at high risk aversion is lower than at low risk aversion, is caused by reductions in pasture area on relatively productive soils, leading to lower average pasture production per hectare of pasture.

TABLE 3

Sensitivity of Stocking Rate to Wool Price

Wool price (per greasy kg net on farm)	Risk aversion		
	Nil	Low	High
130	1.2	1.4	1.4
210	1.4	1.6	1.7
290	1.8	2.0	1.9
370	1.9	2.1	2.6
450	2.1	2.4	2.6

To illustrate the importance of supplementary grain feeding in achieving the higher stocking rates selected under risk aversion, Table 4 shows the level of grain fed in each season type. The expected level of grain feeding is approximately 45% higher under risk aversion than under risk neutrality. Season 9 has the highest requirement for supplementary feeding, particularly under low risk aversion. The requirement is a little less under high risk aversion due to the lower stocking rate, but higher is seasons 2, 5, 7 and 8 due to the change in rotations discussed above. This result is peculiar to the wool price of 290c/kg, as indicated in Table 3.

TABLE 4

Level of Supplementary Grain Feeding (Tonnes)

Season	Risk aversion		
	Nil	Low	High
1	3.8	3.9	3.8
2	6.3	6.6	8.2
3	30.2	31.5	28.0
4	6.1	30.8	23.0
5	7.2	11.0	17.7
6	3.8	3.9	3.8
7	3.7	3.8	11.1
8	17.7	27.1	36.8
9	47.7	74.3	50.3
Expected value	13.1	18.9	18.0

The combined effect on profit of these changes in pasture area, rotation, stocking rate and supplementary feeding is shown in Table 5. The variation in net cash surplus over different seasons is very large, ranging from over $200,000 surplus in season 1 to deficits in seasons 8 and 9. The impact of risk aversion on the distribution of cash surplus is as expected; risk aversion reduces both the expected value and standard deviation of income.

TABLE 5

Probability Distribution of Net Cash Surplus ($'000) in Optimal Solutions

Season	Probability	Risk aversion		
		Nil	Low	High
1	0.17	237	235	[illegible]
2	0.12	153	144	132
3	0.08	8	7	4
4	0.05	183	172	166
5	0.12	42	38	37
6	0.13	100	92	84
7	0.09	22	21	18
8	0.14	-14	-9	-5
9	0.10	-36	-17	-15
Expected value		83	82	77
Standard deviation		94	89	83

The cost of risk (the reduction in expected income which a risk averse decision maker is willing to accept in order to reduce income variation) is around $1,000 for low risk aversion but over $6,000 for high risk aversion. These values are very dependent on the wool price, as shown in Table 6. In fact the figure of $6,000 for high risk aversion is relatively low. The cost is substantially higher at both lower and higher wool prices. This may be explicable in terms of the importance of achieving risk reductions and the cost of doing so. In poor seasons the model selects tactical reductions in the area of crop to avoid the risk of very poor yields on some soil types (Kingwell et al. 1991). Thus income in these poor seasons is strongly dependent on wool. Very low wool prices, thus have a disproportionately large negative impact on utility in the poorest seasons. Consequently reductions in risk are very important to risk averse decision makers when wool prices are low, and they are prepared to sacrifice large amounts of expected income to achieve reductions in income variance.

On the other hand, at higher wool prices, risk reductions are not such an imperative. However at very high wool prices, the reduction in income variation which can be "purchased" for a dollar worth of expected income is much higher. At 130c/kg, a dollar of expected income must be traded off against just over a $1 reduction in standard deviation of income, while at 450c/kg, a dollar of expected income buys $2.50 of standard deviation. Given the lower price of risk reductions at high wool prices, the risk averse farmer chooses to purchase more.

TABLE 6

Impact of high risk aversion in reducing expected value and standard deviation of net cash surplus

Wool price (per greasy kg net on farm)	Cost of risk[a]	Reduction in standard deviation
130	17.3	18.3
210	9.18	12.7
290	6.35	10.7
370	10.9	21.5
450	14.3	35.7

[a]Reduction in expected value of cash surplus.

The final set of results shows the impact of risk aversion on the own price elasticity of supply for wool. Elasticities are obtained by solving the model for a range of prices and regressing these prices against the expected value of quantities produced (using OLS). This is another result which differs from findings already in the literature (e.g. Fraser 1990). This result is probably related to the observed increase is stocking rate under risk aversion. Higher stocking rates makes profit per hectare more sensitive to the wool price and so increases sensitivity of quantity supplied to price. This effect would be somewhat offset by inclusion of price uncertainty in the model. There is likely to be little covariance between wool price and grain prices, producing an incentive to diversify production (Johnson 1967; Just and Zilberman 1986) and reducing responsiveness to price for both wool and grains. We plan to examine this issue when price uncertainty is included in the model later in 1991.

TABLE 7

Own Price Supply Elasticity For Wool at 290c per Greasy kg

	Risk aversion		
	Nil	Low	High
Elasticity	0.65	1.06	1.60

Concluding Comments

A key finding of the study is the importance of grain storage as a means of reducing risk. Large storage capacity allows grain produced in good seasons to be transfered to poor seasons, increasing overall stocking capacity and reducing income variability. This strategy results in a number of management changes which conflict with conventional wisdom or results in the literature on the impact of risk aversion on optimal sheep management strategies. We have found that under risk aversion: pasture area decreases, stocking rate increases and supply elasticity increases. We have suggested that the pasture area and supply elasticity results would at least be moderated, if not reversed, by the inclusion of price uncertainty in the model, in addition to the climatic variability already modelled.

References

Bardsley, P. and M. Harris (1987) "An Approach to the Econometric Estimation of Attitudes to Risk in Agriculture." *Aust. J. Agr. Econ.* 31: 112-26.

Bond, G. and B. Wonder (1980) "Risk Attitudes Amongst Australian Farmers." *Aust. J. Agr. Econ.* 24: 16-34.

Brown, C.G. and R.G. Drynan (1986) "Plant Location Analysis Using Discrete Stochastic Programming." *Aust. J. Agr. Econ.* 30: 1-22.

Cocks, K.D. (1968) "Discrete Stochastic Programming." *Manago. Sci.* 15: 72-9.

Fraser, R.W. (1990) " Producer Risk, Product Complementarity and Product Diversification." *J. Agr. Econ.* 41: 103-7.

Garoian, L., J.R. Conner and C.J. Scifres (1987) "A Discrete Stochastic Programming Model to Estimate Optimal Burning Schedules on Rangeland." *S. J. Agr. Econ.* 19: 53-60.

Ghadim, A.K.A. and D.J. Pannell (1991) "Economic trade-off between pasture production and crop weed control." *Agr. Syst.* (in press).

Johnson, S.R. (1967) "A Re-examination of the Product Diversification Problem." *J. Product Econ.* 49: 610-21.

Just, R.E. and Zilberman, D. (1986) "Does the Law of Supply Hold Under Uncertainty?" *Econ. J.* 96: 514-24.

Kingwell, R.S. (1987) "A Detailed Description of MIDAS." *MIDAS, A Bioeconomic Model of a Dryland Farm System*, ed. R.S. Kingwell and D.J. Pannell. Wageningen: Pudoc.

Kingwell, R.S. and D.J. Pannell, eds. (1987) *MIDAS, A Bioeconomic Model of a Dryland Farm System.* Wageningen: Pudoc.

Kingwell, R.S., D.A. Morrison and A.D. Bathgate (1991) "MUDAS: Model of an Uncertain Dryland Agricultural System." *Agr. Syst.* (in press).

Lambert, D.K. (1989) "Calf Retention and Production Decisions Over Time." *W. J. Agr. Econ.* 14: 9-19.

Lambert, D.K. and B.A. McCarl (1989) "Sequential Modeling of White Wheat Marketing Strategies." *N. Cent. J. Agr. Econ.* 11: 105-15.

McArthur, I.D. and J.L. Dillon (1971) "Risk, Utility and Stocking Rate." *Aust. J. Agr. Econ.* 15: 20-35.

Morrison, D.A., R.S. Kingwell, D.J. Pannell and M.A. Ewing (1986) "A Mathematical Programming Model of a Crop-Livestock Farm System." *Agr. Syst.* 20: 243-68.

Pannell, D.J. (1990) *MARG, MP Automatic Run Generator.* Perth: Western Australian Department of Agriculture.

Pannell, D.J. and F.D. Panetta (1986) "Estimating the On-Farm Cost of Skeleton Weed (*Chondrilla juncea*) in Western Australia Using a Wholefarm Programming Model." *Agr. Ecosyst. Environ.* 17: 213-27.

Patten, L.H., J.B. Hardaker and D.J. Pannell (1988) "Utility Efficient Programming for Whole-Farm Planning." *Aust. J. Agr. Econ.* 32: 88-97.

Rae, A.N. (1971a) "Stochastic Programming, Utility and Sequential Decision Problems in Farm Management." *Amer. J. Agr. Econ.* 53: 448-60.

Rae, A.N. (1971b) "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." *Amer. J. Agr. Econ.* 53: 625-38.