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Impacts of risk aversion on whole-farm management in Syria†

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This article reports on a study of the impact of risk on farm management practices in northern Syria, focusing particularly on how these are affected by risk aversion and farm size. The study is based on production data from an eight-year field trial and on prices from market surveys. A large linear programming model is built, representing the eight years as observations from a discrete probability distribution. Risk aversion is modelled by inclusion of a utility function with constant relative risk aversion, represented using the DEMP/UEP approach.

1. Introduction

Modern Syria is situated in the region where agriculture was first practised, around 10 000 years ago. The region is the centre of origin for major agricultural species such as wheat, barley, lentil, vetch and sheep, and Syrian dryland agriculture is still substantially based on these. It is also characterised by low productivity of labour (by Western standards) and high variability of yields.

Low and variable yields, small farm sizes and the absence of market instruments for risk management combine to make risk an issue of importance to Syrian farmers. Nguyen (1989) observed that 'few countries experience such an extraordinarily high degree of variability in national cereal production as Syria', and that this variability is 'a long-standing phenomenon and originate[s] largely from Syria's highly variable rainfall'. There have been analyses of optimal management under risk aversion for

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individual farm inputs (e.g. Mazid and Bailey 1992) but previous economic analyses of whole-farm management problems in Syria (e.g. Nordblom *et al.* 1994) have failed to consider risk. Here we present a case study of optimal farm management systems in north-west Syria under various degrees of risk aversion. The analysis is based on a whole-farm linear programming (LP) model incorporating a discrete joint probability distribution of yields and prices. The model is constructed to identify farming practices (e.g. choice of crop species, livestock flock size) which provide an optimal balance between profit and risk for farmers with different degrees of risk aversion. The problem represented parallels that faced by Australian farmers in regions of Mediterranean climate (e.g. Kingwell 1994).

Our objectives are to identify (a) which management practices are sensitive to risk aversion, (b) how optimal practices are affected by the degree of risk aversion and (c) how the impact of risk aversion varies on farms of different sizes. The contributions of the article are in its empirical results and its demonstration of the DEMP/UEP technique (Lambert and McCarl 1985; Patten *et al.* 1988). This article is one of the first empirical applications of this method to represent risk aversion.

2. The model

Past strict government controls requiring farmers to maintain particular crop mixes, with emphasis on wheat, have been relaxed recently, allowing new freedoms of private choice. The decision problem for Syrian farmers now is to select a combination of farm enterprises, rotations, sheep flock size, stocking rate and feeding strategies subject to their sets of biological, technical and resource constraints. A deterministic LP model addressing this problem is described in detail by Nordblom *et al.* (1992) and an application is presented by Nordblom *et al.* (1994). In this study we extend and substantially expand that model to represent riskiness of production, riskiness of prices and risk-aversion on the part of the farmer.

The main groups of activities in the model are as follows:

1. Rotation activities. All are two-year rotations in which a cereal crop alternates with another enterprise, these being lentils, vetch, fallow, watermelon and medic pasture. The cereal is wheat, except in the medic rotation where the cereal may be wheat or barley.
2. Feeding activities in each season of the year. Possible feeds include crop residues, grain, pasture, hay and straw.
3. Product sale activities.
4. Sheep activities.

5. Labour market activities. Labour may be hired to meet seasonal shortages and family labour hired out during times of excess labour availability.
6. Cash-flow activities.
7. Utility accounting activities.

The main constraints are as follows:

1. Land constraint: farm sizes of 16 and 64 hectares are considered since most farms in the area fall within this range. A survey showed that only 8 per cent of farms have more than 80 hectares (Khazma 1992).
2. Labour constraints: there is one constraint on labour availability in each of six periods of the year: autumn, winter, spring, harvest (in late spring), early summer and late summer. Family labour may be supplemented with hired labour at times of peak need in some solutions of the model.
3. Utility and income accounting constraints: there are wealth and utility constraints for each year of the model. They are used to calculate final wealth for each year and to link this to a utility function in the objective function.
4. Crop product constraints (and transfers): sales and uses of the various crop products are tied to production activities by transfer rows. Each of the rotations produces wheat or barley grain and straw. We assume at most 80 per cent of the straw biomass can be collected (for sale or feeding in other seasons) with 20 per cent lost to shattering and trampling. If wheat stubble is grazed in summer, we assume a maximum of 75 per cent can be consumed by sheep, with the remainder lost to trampling and shattering. Where stubble grazing is deferred until autumn, these losses increase to 50 per cent. An alternative use of straw in the field is to sell it for grazing in late summer. Lentil straw is generated as a by-product of the hand-harvested crop. It can be fed to the farmer's own sheep in any of the four feeding seasons of the year, or sold to others, with quantities controlled in a single constraint. Fresh watermelon production is sold through a sales activity, controlled by a single transfer constraint. The three options for use of a vetch crop after it has been established have their quantities limited in a single row. Medic pasture production and offtake are controlled by four constraints per year, one for each feeding season.
5. Feed quantity and quality constraints for sheep: limits on maximum dry matter intake, and minimum crude protein and metabolisable energy levels are defined in the model on a per-ewe basis, season-by-season. The model calculates the least-cost diets for the whole-farm, balancing stored and purchased feeds with seasonal pastures and crop residues over time.

6. Constraints on consumption of cottonseed cake: for each of the four feeding periods in each season, cottonseed cake cannot exceed 10 per cent of the diet.
7. Livestock product transfer constraints: a flock of Awassi ewes is assumed to have four marketable products (milk, weaned lambs, fattened lambs and culled ewes). Wool is a product of insignificant economic importance in the region, so it is not represented in the model. There are sales activities in each year linked to the EWE activity by transfer rows.
8. Constraints on shepherd and sheep: for some runs of the model it is desirable to remove sheep, and the commitments of shepherding time, from consideration. This has the effect of freeing family labour for other uses on the farm or in off-farm employment. A constraint sets the level of labour use by sheep to appropriate levels for shepherding or to zero if sheep are excluded.
9. The one-family constraint: the family's minimum cash needs for essential purchases are specified in the FAMILY activity which is constrained to exactly one unit. This activity also provides quantities of labour which can be supplemented with hired labour if necessary.

2.1 Data

Biological data were obtained over eight years (the 1985–86 to 1992–93 growing seasons) from L13, a long-running rotation trial conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA) at its Tel Hadya research station in north-west Syria. The site has a Mediterranean climate with average annual rainfall of 330 mm. Table 1 shows means and coefficients of variation (CVs) of output of each of the products represented in the model. These are calculated from the eight years of data collected from the trial. Coefficients of variation are higher than those estimated by Nguyen (1989) for this region. For example, Nguyen (1989) reported CVs of wheat yield for Aleppo (a city in the study region) of 25 per cent for 1971–81. Nguyen's lower value probably arises primarily because the aggregation of yields of many farmers in the region reduces the observed variance somewhat.

The coefficients of determination for yields of selected enterprises are shown in table 2. (Note that correlations are positive in each case.) These values are potentially important influences on management when the farmer is risk averse. Enterprises with low correlations may offer opportunities for income stabilisation through diversification. This will be investigated later in the article.

Table 1 Annual yields of various production options

Product	Category		Mean (kg/ha)	CV[a] (%)
Medic pasture	Low stocking level	Winter	50	150
		Spring	478	50
		Summer	201	95
		Autumn	19	175
	Medium stocking level	Winter	87	151
		Spring	717	50
		Summer	300	98
		Autumn	17	227
	High stocking level	Winter	102	132
		Spring	949	57
		Summer	373	111
		Autumn	3	265
Wheat grain	Fallow–wheat rotation		2530	49
	Water melon–wheat rotation		2569	49
	Vetch–wheat rotation		1768	49
	Lentil–wheat rotation		1837	46
	Medic (low)–wheat rotation		1469	61
	Medic (med)–wheat rotation		1449	58
	Medic (high)–wheat rotation		1629	58
Barley grain	Medic (low)–barley rotation		2892	60
	Medic (med)–barley rotation		2669	59
	Medic (high)–barley rotation		2751	59
Water melon			2186	86
Vetch hay			932	48
Vetch stubble			389	48
Vetch seed			829	68
Vetch straw			1499	56
Vetch pasture			1548	48
Lentil grain			1101	46
Lentil straw			1814	51

Note: [a] Coefficient of variation
Source: ICARDA experiment L13, Tel Hadya, Syria, 1985-86 to 1992-93

Table 2 Correlation (R^2) between yields of selected enterprises

Enterprise	Medic[a]	Lentils	Wheat[b]	Barley[a]	Water melon	Vetch
Medic[a]	1.00					
Lentils	0.13	1.00				
Wheat[b]	0.32	0.76	1.00			
Barley[a]	0.33	0.70	0.88	1.00		
Water melon	0.48	0.79	0.91	0.87	1.00	
Vetch	0.11	0.89	0.70	0.52	0.72	1.00

Notes: [a] Based on medic–barley rotation.
[b] Based on lentil–wheat rotation.
Source: ICARDA experiment L13, Tel Hadya, Syria, 1985–86 to 1992–93.

Table 3 Purchase and sale prices of various products

Product	Mean (1992 SL/kg)	CV[a] (%)
Barley grain purchase	7.97	21
Barley grain sale	7.97	21
Cottonseed cake	10.14	24
Wheat grain sale	10.40	7
Vetch hay sale	1.52	28
Vetch grain sale	12.03	15
Vetch straw sale	2.53	28
Lentil grain sale	14.74	8
Lentil straw sale	2.25	33
Water melon sale	2.98	34
Milk sale	21.50	16
Lamb sale/purch (spring)	92.02	18
Cull ewe sale	60.52	22
Lamb sale (early summer)	83.55	16

Note: [a] Coefficient of variation.
Source: ICARDA survey of city markets, Aleppo, Syria, 1985–86 to 1992–93.

Prices and costs are from annual records of market prices at Aleppo and from annual farmer interviews in the area. Price data are included for the same eight years for which there are biological data. They are inflated or deflated to be expressed in 1992 terms. Means and CVs are shown in table 3. Note that transport costs are accounted for separately.

We assume that feed is stored for use within a year but is not stored from year to year, consistent with usual farm practice in the region. Our model represents sedentary sheep, maintained with feed from the farm and with no access to feeds or grazing from other areas, except purchased feeds. We assume that control of grazing is by shepherd and that sheep stay on the farm all year round. Finally we assume that the farmer has no opportunities for investing capital off farm.

2.2 Matrix structure

Activities, constraints and data for the first six years of the trial are presented in detail by Nordblom *et al.* (1992) and in summary by Nordblom *et al.* (1994). As in that study, the decision problem here is to find a steady-state equilibrium strategy which maximises the objective function. This is a widely used approach in whole-farm modelling (e.g. Morrison *et al.* 1986; Kingwell and Pannell 1987; Kingwell 1994). It has the advantage of efficiency in that it allows representation of inter-year effects within a much smaller matrix than is needed for a multiperiod model. Its chief disadvantage is that it does not allow identification of the optimal time path between the initial condition and the steady state optimum. Where one is not attempting to advise an individual farmer, this is not usually a serious limitation.

The matrix represents a single year. However, an important feature of the farming system is that the rotations represented involve sequences of enterprises (i.e. crops and pastures) which take more than one year to complete. These rotational sequences are represented by assuming that an appropriate proportion of the land is devoted to each enterprise in every year. Inter-year impacts, such as carry over of nitrogen from legumes to cereal crops, are captured because yields in the current year for a given rotation are specified on the basis that the rotation has also been practised in the preceding years.

The model developed for this study (called L13R) differs from the previous model (L13) in the following important ways: (a) two additional years of biological and economic data are included; (b) L13 is a deterministic model based on mean values of parameters, whereas L13R is a discrete stochastic programming model, representing each of the eight available years of data as a discrete probability distribution; (c) the models' objective functions differ; L13 maximises expected profit whereas L13R maximises expected utility; and (d) L13R allows division of the farm area into a portfolio of rotations, whereas L13 was constrained to select one rotation for the entire farm.

The model structure is based on discrete stochastic programming (DSP) (Cocks 1968), but multistage decision-making is limited to decisions made within the year which the model represents. These intra-year 'tactical' decisions are those relating to sheep stocking rate and feeding.

The model incorporates eight discrete states of nature; that is, eight year-types corresponding to years for which yield and price data are available. The levels of inter-year carry over effects (e.g. nitrogen fixation) represented in the model are those which actually occurred in the eight years of the trial. It is acknowledged that eight years is a relatively short sample of years on which to base long-term decisions, but it is defended on the basis that the data are of excellent quality and unusual in detail, and that further years of data simply are not available.

The eight year-types are assumed to have equal probabilities of occurrence in the year which the model represents, and to be a representative sample reflecting the variances and covariances between all variables. In this respect, the approach is similar to MOTAD (Hazell 1971). However, unlike MOTAD, risk aversion is represented in the model by the inclusion of a segmented linear approximation of a utility function. Thus we employ a linear approximation of the 'Direct Expected utility maximising Mathematical Programming' (DEMP) approach (Lambert and McCarl 1985) with the model structure being very similar to that employed in 'Utility Efficient

Programming' (UEP) (Patten *et al.* 1988). Hardaker *et al.* (1991) reviewed the available techniques for representing risk aversion in mathematical programming models. They concluded that DEMP/UEP is preferable to other available methods: quadratic programming (e.g. Bhende and Venkataram 1994), MOTAD (Hazell 1971), Target MOTAD (McCamley and Kliebenstein 1987) and mean-Gini programming (Okunev and Dillon 1988).

The model formulation is:

$$\text{Max}\, E[U] = p'U(w) \tag{1}$$

subject to

$$\begin{aligned} &Ax \leq b \\ &-Cx + Iw = f \\ &\text{and } 0 \leq x \end{aligned}$$

where:

- $E[.]$ denotes expectation;
- $U(.)$ is a monotonic concave function representing utility of wealth;
- p is an s by 1 vector of state probabilities;
- w is an s by 1 vector of final wealth by state;
- $U(w)$ is an s by 1 vector of utilities of net incomes by state;
- A is an m by n matrix of technical coefficients;
- x is an n by 1 vector of activity levels;
- b is an m by 1 vector of constraint limits;
- C is an s by n matrix of activity net revenues by state (row) and activity (column);
- f is an s by 1 vector of initial wealth minus fixed costs (identical for each state).

There are two types of activities in the A matrix: tactical and strategic. Tactical activities are those which are specific to a particular type of year (e.g. sheep feeding activities for that year-type). As stated earlier, there are eight year-types represented in the model, each based on a year of real data. For each tactical activity represented in the model, there are eight decision variables: one for each year-type. These activities affect constraints and utility only in their particular year-type.

Strategic activities appear once in the model but have impacts in all year-types. The strategic variables in L13R are those representing alternative crop:crop or crop:pasture rotations, hire of permanent shepherds and the supply of family labour. In representing rotation as a strategic variable, we are assuming that the farmer, having chosen a portfolio of rotations, does not alter it in response to the observed climatic or market conditions in a particular year.

Figure 1 shows a diagramatic overview of the matrix structure. Coefficients for the tactical activities form a block diagonal structure, with strategic activities grouped together at the left. Each of the sub-matrices on the block diagonal has the same structure and each is similar to the deterministic model of Nordblom *et al.* (1994). Table 4 shows an overview of the structure for one year. The strategic activities are included on the left of the matrix. Refer to Nordblom *et al.* (1994) for further description and discussion of the structure used for this sub-matrix.

Kingwell (1994) describes a model of a Western Australian agricultural system which uses the formulation in equation 1. Like us, he implemented the utility variables as segmented linear approximations. By employing an LP framework, we take advantage of the greater speed and reliability of LP relative to non-linear programming, an important factor given the size of our model (430 constraints, 750 activities) and the large number of solutions we generate.

2.3 Utility

A key strength of the model formulation used is its ability to represent any distribution of income and any concave form of the utility function. We employ the following functional form for utility:

$$U = \alpha + \beta W^{1-R}$$

where U is utility, W is wealth, R is relative risk aversion and α and β are parameters.[1] This form is characterised by constant relative risk aversion (CRRA) and, thus, decreasing absolute risk aversion (Hey 1979), meaning that as wealth increases, the behaviour of a decision-maker is less influenced by the degree of risk faced. Various authors have argued on the basis of empirical evidence (e.g. Hamal and Anderson 1982; Pope and Just 1991) or introspection that a realistic utility function should exhibit decreasing absolute risk aversion.

Another advantage of our approach is that it allows the identification of a stochastically efficient set of strategies, so that results are relevant to decision-makers with a range of risk attitudes. Like Patten *et al.* (1988) we generate a number of solutions, each of which is optimal for a particular value of the risk aversion coefficient. Unlike Patten *et al.* (1988) we do not

[1] The values of these parameters make no difference to the utility-maximising strategy since the utility function is 'unique only up to a linear transformation' (Anderson, Dillon and Hardaker 1977).

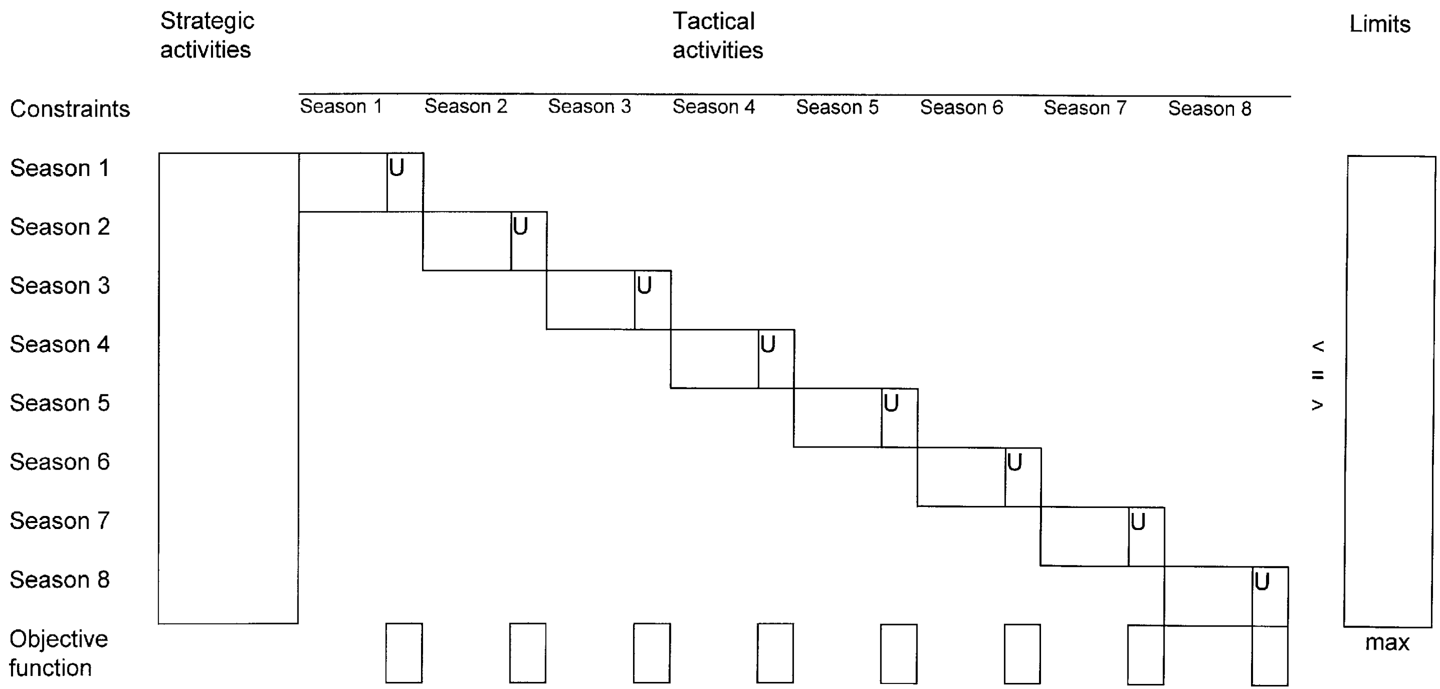

Figure 1 Overview of matrix structure

Table 4 Summary of linear programming sub-matrix

		Strategic activities				Tactical activities									
		Family (–) 1	Shepherd (flock) 1	Ewes (head) 1	Rotation (ha) 10	Graze medic (kg) 4	Sell or feed crop outputs (kg) 46	Feed cotton-seed cake (kg) 4	Milk sale (kg) 1	Lamb sale (kg) 1	Cull ewe sale (kg) 1	Hire or sell labour (days) 10	Credit or debt (SL) 10		Limit
Objective (SL)	1												1/ − 1		max
Land (ha)	1				1									L	16
Labour (days)	5	−a	a	a	a			a	a			−1/1		L	0
Cash tr (SL)	5	a		a	a		−a	a	−a	−a	−a	a/ − a	1/ − 1	L	0
Crop outputs (kg)	11				−a		1							L	0
Medic tr (kg)	4				−a	1								L	0
Intake (kg)	4			−a		1	1	1						L	0
Energy (MJ)	4			a		−a	−a	−a						L	0
Protein (kg)	4			a		−a	−a	−a						L	0
Cotton CS lim (kg)	4			−a				1						L	0
Milk tr (kg)	1			−a					1					L	0
Lamb tr (kg)	1			−a						1				L	0
Cull ewe tr (kg)	1			−a							1			L	0
Family (–)	1	1												E	1
Shep lim (flock)	1		1											E	1
Ewe lim (head)	1		−a	1										L	0

Notes:
1. Numbers next to row/column headings indicate numbers of rows/columns in the sub-matrix.
2. a and −a represent positive and negative coefficients respectively.
Source: Linear programming matrix developed for the analysis discussed in the text.

employ parametric programming on a two-part utility function, but rather obtain an efficient set of solutions by varying the risk aversion coefficient over a defined range. Each of our solutions would be part of the efficient set derived using a method such as Stochastic Dominance With Respect to a Function (SDWRF) (Meyer 1977), but because SDWRF operates by pair-wise comparisons, the number of possible strategies which we are practically able to compare is vastly greater. The cost of this convenience is that we do not necessarily identify all solutions in the efficient set, merely a representative group of solutions corresponding to particular risk aversion coefficients. However, for practical purposes we believe this to be adequate.

The range of relative risk aversion coefficients examined in this study is between zero (risk neutral) and 4 (extremely risk averse). This range is consistent with empirical evidence about farmers' risk attitudes elsewhere and theoretical arguments from a range of sources (Antle 1987; Arrow 1971; Bardsley and Harris 1987; Binswanger 1980; Bond and Wonder 1980; Myers 1989; Newbery and Stiglitz 1981).

Copies of the matrix data file (L13R8.MPS) and a set of spreadsheet files used to calculate matrix coefficients are available from the authors on request.

3. Results and discussion

Table 5 is a list of abbreviations used to represent different rotations in later tables and figures. Those rotations without an 'n' in their abbreviation do include sheep. Table 6 shows a brief summary of the main farm activities for a version of the model with 16 hectares of land (which is close to the average farm size for the modelled region) and a risk-neutral farmer (i.e. one with the objective of maximising expected profit). The expected-profit-maximising farm strategy includes 14.3 hectares of lentil–wheat rotation and 1.7 hectares

Table 5 Abbreviations used for rotation names in figures 4 and 5 and table 6

Abbreviation	Description
L	Lentil–wheat rotation
V	Vetch–wheat rotation
F	Fallow–wheat rotation
W	Water melon–wheat rotation
M	Medic pasture–wheat rotation
Mb	Medic pasture–barley rotation
Ln	Lentil–wheat rotation with no sheep
Vn	Vetch–wheat rotation with no sheep
Fn	Fallow–wheat rotation with no sheep
Wn	Water melon–wheat rotation with no sheep

Table 6 Summary of optimal farm activities for risk-neutral farmer

Item	Unit	Annual value
Rotations	(ha)	
L		14.3
V		0.0
F		0.0
W		0.0
M		0.0
Mb		1.7
Ln		0.0
Vn		0.0
Fn		0.0
Wn		0.0
Ewes	(head)	40
Lambs sold	(kg)	640
Milk sold	(kg)	2000

Source: the analysis discussed in the text.

Table 7 Summary of optimal feeding and labour hiring activities for risk-neutral farmer

Activity	Unit	Optimal level							
Year-type		1	2	3	4	5	6	7	8
Feed barley	(kg)	5619	5376	4426	7031	3993	5628	4927	5380
Feed cottonseed cake	(kg)	266	183	27	2054	1933	359	266	301
Hire labour	(days)	42	80	125	0	0	0	34	65

Source: the analysis discussed in the text.

of medic–barley rotation. This partial diversification is due to resource constraints, not to risk aversion.

From the same optimal solution, table 7 shows results for the feeding and labour-hiring sections of the model. Table 7 highlights some of the variability inherent in this farming system. The levels of cottonseed cake fed to sheep and the levels of hired labour vary dramatically depending on production levels of the farm's enterprises in particular types of year.

Figure 2 shows the optimal allocation of land to different rotations for farmers with 16 hectares of land and for levels of relative risk aversion (RRA) ranging from zero to 4.0. The result for a risk aversion coefficient of zero is the same as that shown in table 6, with most land allocated to lentil–wheat rotation with a small area of medic–barley rotation. At RRA of 0.8 the solution includes a slightly greater area of medic–barley rotation, but at higher levels of risk aversion, medic–barley rotation drops completely out of the solution to be partly replaced by water melon–wheat rotation.

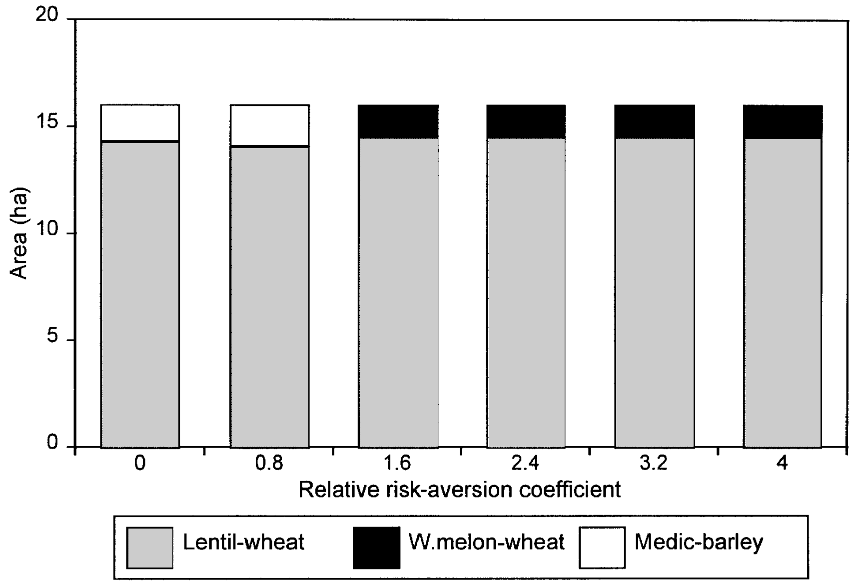

Figure 2 Optimal land allocation for 16-hectare farm

Another associated change not apparent from this graph is that solutions for risk aversion of 1.6 or greater do not include any sheep. Sheep are profitable, but the variance of that profit is relatively high. At higher risk aversion, sheep are not included in the solution, and without sheep, medic is not grown (since its main value is as a sheep feed).

Figure 3 is equivalent to figure 2 except that it shows results for a larger farm of 64 hectares, which is in the top quarter of farm sizes in the region. In this case, sheep remain in the solution even at the highest level of risk aversion. The optimal area allocated to medic–barley rotation increases with increasing risk aversion until it occupies 39 per cent of the farm when RRA equals 4.0. In addition, all solutions with RRA greater than zero include an area of water melon–wheat rotation. Thus the farm is highly diversified, with five different plant species grown in three different rotations. The range of goods sold off the farm includes wheat grain, wheat straw, wheat stubble,[2] barley grain, barley stubble, lentil grain, lentil straw, water melons, sheep milk, lambs (in spring), lambs (in early summer), adult ewes, and surplus labour. This diversification helps to reduce risk, since the probability distributions of net returns from these various products are less than perfectly correlated.

[2] Standing crop residues following grain harvest sold as sheep feed.

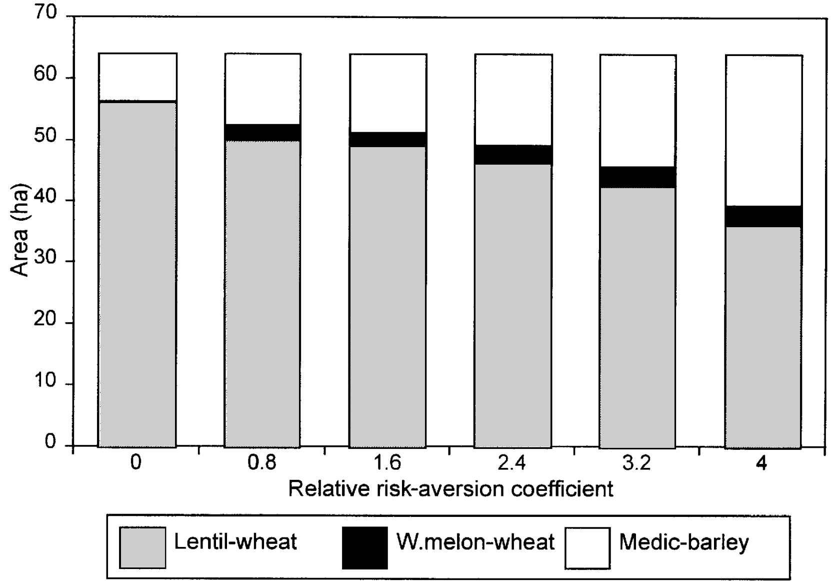

Figure 3 Optimal land allocation for 64-hectare farm

Consider the question of why sheep (and thus medic) remain in the solution for the 64-hectare farm, even at high risk aversion. The reason relates to the efficiency of labour use for medic. Based on observations from the region, we assume that on the larger farm, the availability of family labour is no greater than on the smaller farm. Given the larger total areas of crops (especially of lentil which is very labour intensive at harvest time), the optimal farm plan for the 64-hectare farm includes high levels of hired labour. Because medic requires relatively low input of labour compared to the cropping enterprises, its relative advantage is increased. Furthermore, a larger sheep flock requires a less than proportional increase in labour for shepherding. These benefits are sufficient to justify maintaining a sheep flock, despite the variability of sheep income.

The other feature of figure 3 is the way the optimal area of medic–barley rotation increases with increasing risk aversion. This is primarily a result of the low correlation between production of medic and production of crops. For example, table 2 shows that the R^2 for medic offtake and lentil grain production is only 0.13. Table 8 shows R^2 for net returns from different rotations. The correlation between lentil–wheat and medic–barley is among the lowest, at 0.75. Thus inclusion of medic on the farm contributes to stabilisation of income on the farm. The greater the degree of risk aversion, the greater the value placed on this stabilisation and so the greater the area of medic.

Table 8 Correlations (R^2) between net returns for main rotations

Enterprise	Fallow–wheat	Lentil–wheat	Vetch–wheat	W. melon–wheat	Medic–wheat	Medic–barley
Fallow–wheat	1.00					
Lentil–wheat	0.76	1.00				
Vetch–wheat	0.69	0.97	1.00			
Water melon–wheat	0.90	0.76	0.65	1.00		
Medic–wheat	0.94	0.77	0.74	0.85	1.00	
Medic–barley	0.87	0.75	0.77	0.76	0.96	1.00

Source: the analysis discussed in the text.

Because the variables in our model are not normally distributed and the assumed functional form for our farmers' utility functions is not quadratic, our methodology is superior to an EV analysis (Anderson *et al.* 1977) in its identification of optimal farm plans (Levy and Hanoch 1970). We are able to consider all moments of the distribution of income and to represent the more realistic risk attitude of decreasing absolute risk aversion. Nevertheless, an EV framework does provide a convenient vehicle for presentation of some of our results.

Figure 4 shows an EV graph for the 16-hectare farm. Labelled squares correspond to each of the rotations represented in the model. Expected values and variances of income are calculated for each rotation by specifying a constraint to include 16 hectares of the rotation and solving the constrained model with the objective of maximising expected profit. The

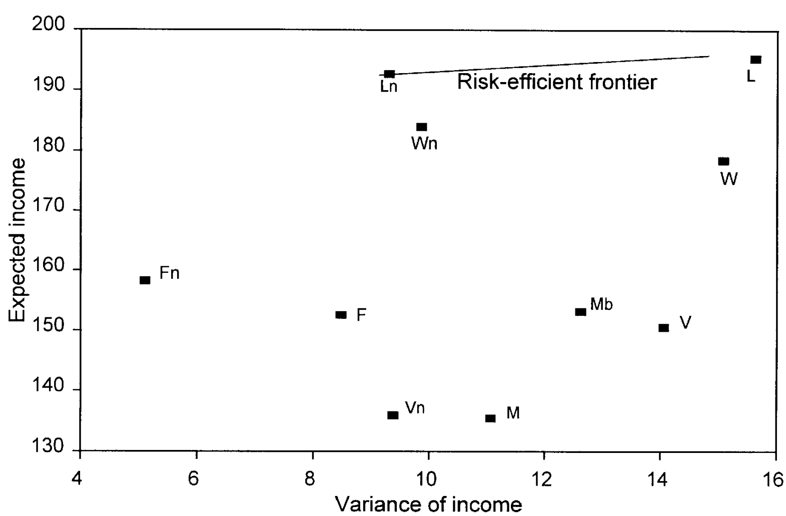

Figure 4 The income:variance trade-off for 16-hectare farm

graph also includes a 'risk-efficient frontier' which corresponds to the solutions illustrated in figure 2 for relative risk aversion coefficients between zero and 4.0. The right-hand end of the risk-efficient frontier is the optimal risk-neutral solution and the left-hand end is for RRA = 4.0.

Figure 4 shows that the rotations vary widely in their expected values and variances of income, with most falling well below the risk-efficient frontier. Despite this, the solutions in figure 2 include two of the rotations which appear inefficient in figure 4. Medic–barley (Mb) is included at low risk aversion because its relatively low labour usage complements the lentil–wheat rotation (L). Thus medic–barley rotation is beneficial to include as a small proportion of the farm even though it would be highly unprofitable to include as a large proportion of the farm. At higher levels of risk aversion, the solution excludes sheep and includes lentil–wheat and water melon–wheat rotations (Ln and Wn, respectively).

Figure 5 is a similar EV graph but for the 64-hectare farm. In this case, the sacrifice of expected income involved in excluding sheep from the farm is too great to be compensated for by the lower variance of income. The rotations illustrated in figure 3 correspond to L (lentil–wheat), W (water melon–wheat) and Mb (medic–barley), of which only L appears near to being risk efficient when the whole farm is constrained to a single rotation.

Even though the risk-efficient frontier includes greater areas of medic–barley rotation as risk aversion increases (towards the left), the fall in E is much less than might be expected considering the result for

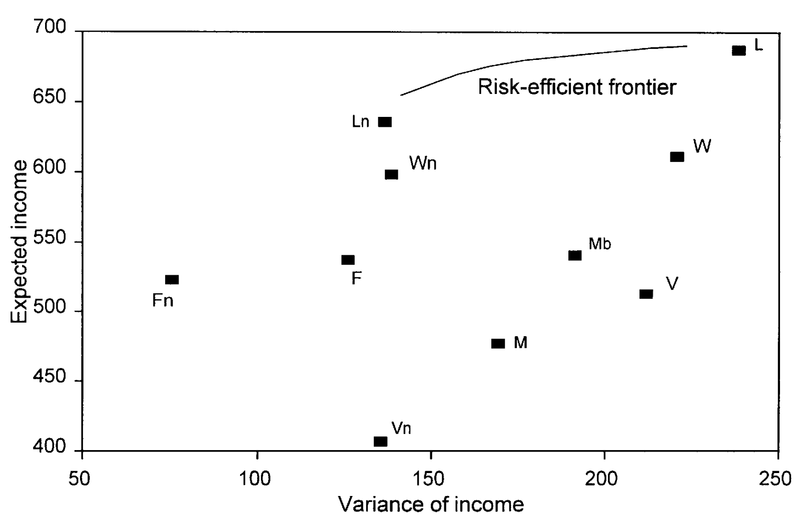

Figure 5 The income:variance trade-off for 64-hectare farm

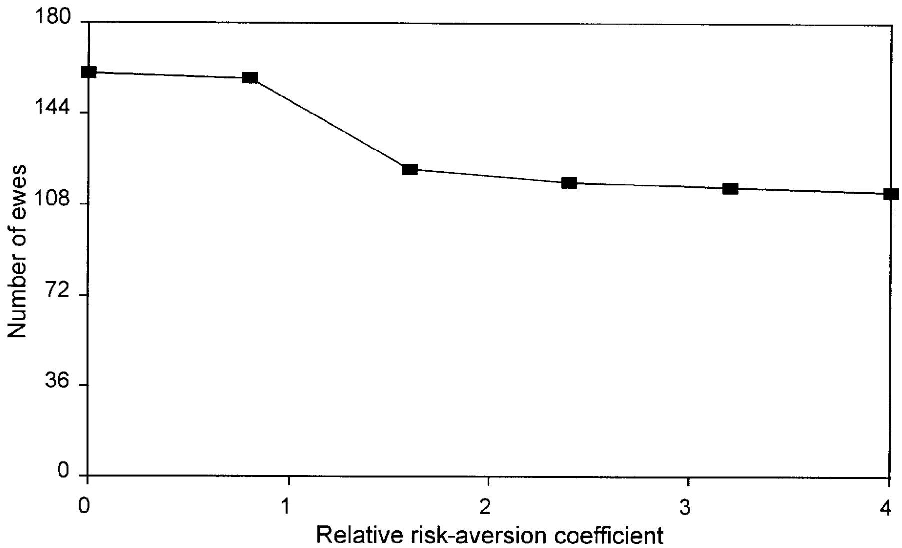

Figure 6 Total ewe numbers

Mb. This is due to the efficiency of resource use allowed by combining enterprises. Furthermore, the fall in variance of income following inclusion of Mb is much greater than might be expected. This reflects the reduction in variance due to diversification as well as other management changes not apparent from this graph. The most important of these is the fall in sheep flock size (see figure 6). The need to purchase feed for sheep in years of low feed production contributes to the riskiness of sheep production. The model calculates that under risk aversion it is optimal to reduce this risk by lowering sheep numbers and increasing the area of medic pasture.

These results illustrate the power and convenience of the DEMP/UEP approach. A simple EV comparison would have concluded that, for both farm sizes, the efficient rotations are L, Ln and Fn. Our analysis has revealed that for the 16-hectare farm, Fn is too unprofitable to be selected for realistic levels of risk aversion, while for the 64-hectare farm, neither Fn nor Ln are included. Furthermore, there are other rotations which are not EV efficient but which are in fact risk efficient when selected as part of an optimal portfolio (medic–barley and water melon–wheat). This reflects important whole-farm resource constraints and benefits of diversification which are easily and conveniently captured with our modelling approach. Our results clearly have limitations, primarily due to the limited sample of eight years of data, but within this constraint the modelling approach appears to have significant advantages.

4. Conclusions

By adopting suitable management practices, farmers in this region are able to reduce risk substantially with little sacrifice in expected income. For both farm sizes in our analysis, the optimal portfolios of rotations include rotations which appear highly inefficient when assessed using simple EV criteria applied to individual rotations. Furthermore, there are EV-efficient rotations which are, in fact, not efficient when assessed using the more theoretically respectable expected utility approach.

The most prominent impacts of risk aversion appear to be on the optimal area of improved pasture and the number of sheep carried. On larger farms, optimal sheep numbers are substantially lower for farmers with high risk aversion while on small farms with abundant labour, only farmers with low risk aversion would own sheep at all.

For farmers with large farms and high risk aversion, lower sheep numbers are a way of reducing the risk of needing to purchase substantial amounts of supplementary feed in poor years. This risk is further reduced by the inclusion of larger areas of medic pasture on the farm. On the larger farm, the model suggests that risk-averse farmers adopt strategies which are much more diversified than their risk-neutral counterparts. Risk-neutral farmers would obtain most of their income from wheat and lentils, while risk-averse farmers in addition obtain a substantial part of their income from barley and sheep products as well as some from water melon.

The result of lower sheep numbers under risk aversion might be altered somewhat if farmers were to adopt the practice of storing reserves of feed across years (an option not currently included in the model). Difficulties of preventing deterioration of stored feed may be the main reason why this is currently not common in Syria. Results presented by Kingwell (1994) for Western Australia suggest that grain storage may be a valuable strategy for managing risk, avoiding the need to reduce sheep numbers.

Farm area has been found to be a very important factor influencing optimal practices under risk aversion. Area interacts with risk aversion to determine the optimal mix of rotations and the optimal flock size.

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