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A WHOLE-FARM MODEL BASED ON EXPERIMENTAL FLOCKS AND CROP ROTATIONS IN NORTHWEST SYRIA

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by

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ABSTRACT

This document describes a whole-farm model based on data from farm scale crop, sheep and native pasture experiments managed by scientists. The data are integrated using linear programming (LP) and tests of the economic viability of intensified production systems are presented.

A six year experiment at Tel Hadya, 30 km SW of Aleppo, Syria, provided data on four rainfed crop rotations: (1) barley-fallow, (2) barley-vetch, (3) wheat-lentil-water melon and (4) wheat-vetch-water melon. "Traditional" rotations (1 and 3 above) were managed as by farmers in the area; "high-input" rotations (2 and 4) incorporated vetch crops for pasture or hay and used "improved" cultural practices and cereal varieties. Experimental flocks of Awassi ewes provided three levels of nutrition-performance data. Preliminary estimates were used for native pasture offtakes, with and without phosphate fertilizer. A farm survey in 1985 provided price data.

The LP model was used to compute optimal solutions for 36 resource and management scenarios. Farm profits with the "high input" rotations were greater than those of the "traditional" rotations under all comparable resource conditions, the former being associated with greater crop yields and sheep numbers. Profits and ewe numbers increased when native pasture was added to the farm, and increased further with fertilized pasture. Optimal ewe numbers declined with a change from low to high nutritional regimes, but farm profits were little affected.

The present analysis suggests the replacement of fallow and lentils by vetch, with judicious management, may lead to more productive and profitable crop-livestock husbandry in environments similar to Tel Hadya.

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CHAPTER 1. INTRODUCTION

Whole-Farm Analysis:

This document describes the first quantitative whole-farm analysis completed at ICARDA. It involves, from both biological and economic viewpoints, the simultaneous consideration of the many interdependent crop and livestock activities on a farm. In order to answer the question, "what is the best crop-livestock management plan for a farm in the Tel Hadya area of northwest Syria", a number of interrelated questions must be considered simultaneously, for example:

> What is the best crop rotation? What is the best way to market the crops, by direct sales or through the sheep? What is the best number of ewes for a farm? What is the best level of sheep nutrition? What is the best way to use the available native pasture? What are the best amounts and types of supplementary feed to purchase?

Certainly, the answers to these resource management questions will depend upon a number of considerations, the first of which is a clear definition of the word "best." It is convenient to consider "whole-farm profit maximization" as the criterion for defining "best." This allows the use of linear programming (LP) techniques to determine a simultaneous set of answers to these questions. LP is an "optimizing" method which can be used to maximize an

objective function, such as whole-farm profits, subject to explicit quantitative constraints.

It is recognized, of course, that farmers may have additional and even more important goals such as risk avoidance or assured family subsistance. But, for the sake of simplicity, we assume a profit-maximizing criterion, and the market orientation it implies. Methods for considering other goals, and especially those dealing with weather-related risks, are discussed in the final chapter.

Quantitative data on the biological and economic relationships which define the farming systems of the area are key prerequisites for answering the above list of questions on what is "best." The basic biological data used in the present study were obtained from an integrated project on crop rotations, sheep and native pasture at ICARDA's Tel Hadya station (36° 01' N, 36° 56' E), 30 km SW of Aleppo. Average annual rainfall at the station is about 330mm.

The "Unit Farm" crop rotations were established in October 1979 with the objective of comparing the traditional rotations of farms in the Tel Hadya area with improved high-input rotations which allow intensified crop and sheep production. Associated with the Unit Farms were three flocks of Awassi ewes, established in June 1981. The three flocks, each containing about 35 ewes, were subjected to low, medium and high nutritional regimes. The low and high regimes were beyond the extremes found in a survey of sheep management in

NW Syria (Thomson and Bahhady, 1983).

A farm survey, conducted in NW Syria in 1985 (Nordblom, forthcoming), provided the economic data for the "whole-farm LP model" described in this document.

Even with all the biological and economic data embodied in the whole-farm LP model, and its simple objective of profit maximization, no resource management recommendations can be offered without reference to a particular set of resource constraints. For example, exactly how much arable land and native pasture land is controlled by the farmer and what soils, shallow or deep, are found on the arable land? In the present study, profit-maximizing solutions are found for 36 different resource and management scenarios.

Objectives:

The three objectives of this document are:

1. to describe the bio-economic parameters of rainfed farming systems in the Tel Hadya area, as needed for a whole-farm analysis;

2. to serve as a reference document for future use of the whole-farm LP model; and

3. to provide training material on resource management in rainfed farming systems.

This document is intended for use by scientists and technicians. It may be used as an illustration of farming

systems in the Tel Hadya area, and of methods applicable to analysis of integrated crop-livestock systems. LP methods allow the consequences of interactions within the farming system to be traced quantitatively, showing that the whole-farm is more than the sum of its parts.

Sufficient detail is given on the data and structure of the model to enable others to repeat the calculations or make their own changes in the model: a computer with any standard LP software package can be used. Such complete documentation is intended to encourage and facilitate further use of bio-economic results through modeling.

CHAPTER 2. BIO-ECONOMIC RELATIONSHIPS

This chapter presents brief summaries and explanations of results from experimental flocks and crop rotations at Tel Hadya, in formats suitable for the linear programming (LP) analysis which follows. Data on native pastures and prices are also presented.

Crop Rotations:

Four crop rotations were studied in the Unit Farm project:

1. Barley-Fallow: traditional two-year rotation on shallow soil;
2. Barley-Vetch: high-input two-year rotation on shallow soil;
3. Wheat-Lentil-Melon: traditional three-year rotation on deep soil; and
4. Wheat-Vetch-Melon: high-input three-year rotation on deep soil.

The crops in these rotations were grown, on plots of 1.5 to 3.5 ha, in each of the six years of the Unit Farm experiment, (ICARDA, 1980). The traditional rotations were managed according to agronomic practices common in the Tel Hadya area while the high-input rotations used improved cereal varieties, improved fertilizer levels, shallow cultivation and a seed drill. Careful records of all inputs and outputs were kept. The crops not only provided data for the whole-farm model, but also most of the feed for the three experimental flocks (Thomson, et al, 1983).

Costs and Crop Yields:

The operations, inputs, direct costs and yields for each crop in the four rotations are summarized in Tables 1 to 4. The "dunnum" (du), one tenth of a hectare (Ø.1 ha), was chosen as the unit of land area in the model because it is the one most used by local farmers. To determine the average cost per year for the two and three year rotations, the sum of the costs for the two or three crops in each rotation is divided by two or three, respectively. Likewise, crop yields, averaged over the six seasons of the experiment, are presented in these tables in kg per dunnum per year. All cost and price figures are given in Syrian Pounds (SL), as prevailing in the summer of 1985 (SL 3.9 = $ 1).

The traditional barley-fallow rotation on shallow soil has the lowest costs and the lowest yields (Table 1). The high-input barley-vetch rotation offers higher yields and more feeding options for somewhat higher costs (Table 2).

A different pattern is found when comparing the three-course rotations on deep soils. The traditional wheat-lentil-melon rotation (Table 3) suffers from the high cost of hand harvesting the lentil crop, and from the lower yields of wheat relative to the high-input wheat-vetch-melon rotation (Table 4). Lentil straw and vetch hay present similar advantages for winter feeding: high nutritional quality and flexibility in the timing of use. However, since the lentil crop is hand harvested, no stubble is available for grazing,

TABLE 1. Barley-Fallow Rotation (BFROT) Costs and Yields

A. Costs: SL/du[1/]

1. **Barley** year

cultivations (2 x SL 5.7)	11.4
seed (10 kg x SL 1.5)	15.0
seeding	2.5
fertilizer: (1 kg N x SL 1.8)	1.8
(4.6 kg phosphate x SL 2.17)	10.0
hand broadcasting	2.1
machine harvest and bagging	20.1
transportation	3.0
straw collection (raking and transport)	6.3
Total Costs in barley year =	72.2

2. **Fallow** year cultivation costs (2 x SL 5.7) 11.4

B. Average Annual Cost of Two-Year Rotation:

(total barley costs + fallow costs) / 2

(SL 72.2 + SL 11.4) / 2 = **SL 41.8/du/year**

C. Average Yields[2/]

	Yield/du/2 years	Yield/du/year
barley grain	127.2 kg DM[3/]	63.6 kg DM
barley straw	68.0 kg DM	34.0 kg DM
barley stubble	89.3 kg DM	44.6 kg DM

1/ SL = Syrian Pounds: SL 3.9 = $ 1 in 1985

du = dunnum = 0.1 hectare

2/ average yield data over six years, from Unit Farm

3/ DM = dry matter

TABLE 2. Barley-Vetch Rotation (BVROT) Costs and Yields

A. Costs:

	SL/du
1. Barley Year	
cultivation (3 x SL 5.7)	17.1
seed (10.3 kg x SL 1.5)	15.5
seeding	2.5
fertilizer: (5.1 kg N x SL 1.8)	9.2
(4.2 kg phosphate x SL 2.17)	9.1
hand broadcasting	2.5
machine harvest and bagging	25.0
transportation	7.2
straw collection (raking and transport)	8.8
total barley cost =	96.9
2. Vetch Year	
cultivation (2 x SL 5.7)	11.4
seed (14 kg) x SL 1.7/kg)	23.8
seeding by hand broadcasting	3.0
fertilizer: (5.1 kg phosphate x SL 2.17)	11.1
hand broadcasting	2.1
total vetch establishment cost =	51.4
Vetch Hay Harvest Costs: **(optional)**	
mowing	10.0
handling, ie., turning	14.0
transport	10.0
total vetch hay harvest costs =	34.0

B. Average Annual Cost of Two-Year Rotation:

(total barley cost + total vetch establishment cost)/2

(SL 96.9 + SL 51.4) / 2 = **SL 74.2/du/year**

C. Average Yields:

	Yield/du/2 years	Yield/du/year
barley grain	219.8 kg DM	109.90 kg DM
barley straw	95.5 kg DM	47.75 kg DM
barley stubble	171.8 kg DM	85.90 kg DM
vetch pasture	250.0 kg DM	125.00 kg DM
or vetch hay	150.0 kg DM	75.00 kg DM
and vetch stubble	62.5 kg DM	31.25 kg DM

TABLE 3. Wheat-Lentil-Melon Rotation (WLMROT) Costs and Yields

A. Costs:

	SL/du
1. **Wheat** Year	
cultivation (2 x SL 5.7)	11.4
seed (12 kg x SL 1.85)	22.2
seeding	3.5
fertilizer: (4.1 kg N x SL 1.8)	7.4
(5.6 kg phosphate x SL 2.17)	12.2
hand broadcasting	2.5
machine harvest and bagging	22.4
transportation	4.8
straw collection (raking and transport)	7.4
total cost of wheat =	93.8
2. **Lentil** Year	
cultivation (3 x SL 5.7)	17.1
seed (12.5 kg x SL 1.77)	22.1
fertilizer: (6.2 kg phosphate x SL 2.17)	13.5
hand broadcasting	2.5
hand harvest labor	75.3
transportation	14.0
threshing, winnowing and bagging	26.0
total cost of lentils =	170.5
3. **Water Melon** Year	
cultivation (4), includes 1 by hand	38.3
seed (0.3 kg x SL 46)	13.8
hand planting	7.5
fertilizer: (1.8 kg N x SL 1.8)	3.2
(4.8 kg phosphate x SL 2.17)	10.4
hand broadcasting	2.5
harvest	6.0
transportation	18.2
total cost of water melons =	99.9

B. Average Annual Cost of Three-Year Rotation:

(wheat costs + lentil costs + water melon costs)/3
(SL 93.8 + SL 170.5 + SL 99.9)/3 = **SL 121.4/du/year**

C. Average Yields:

	Yield/du/3 years	Yield/du/year
wheat grain	171.4 kg DM	57.13 kg DM
wheat straw	80.5 kg DM	26.83 kg DM
wheat stubble	83.3 kg DM	27.80 kg DM
lentil grain	76.1 kg DM	25.37 kg DM
lentil straw	129.4 kg DM	43.13 kg DM
water melon	394.5 kg fresh	0.132 mt

TABLE 4. Wheat-Vetch-Melon Rotation (WVMROT) Costs and Yields

A. Costs:

		SL/du
1. **Wheat** Year		
cultivation	(2 X SL 5.7)	11.4
seed	(11.3 kg x SL 1.85)	20.9
seeding		3.5
fertilizer:	(5.3 kg N x SL 1.8)	9.5
	(4.0 kg phosphate x SL 2.17)	8.7
	hand broadcasting	2.5
machine harvest and bagging		25.2
transportation		7.4
straw collection (raking and transport)		8.9
	total cost of wheat =	98.0
2. **Vetch** Year		
cultivation	(2 x SL 5.7)	11.4
seed	(14 kg x SL 1.7)	23.8
seeding		3.0
fertilizer:	(5.1 kg phosphate x SL 2.17)	11.1
	hand broadcasting	2.1
	total vetch establishment cost =	51.4
Vetch Hay Harvest Costs: **(optional)**		
mowing		13.5
handling, ie., turning		18.9
transport		13.5
	total vetch hay harvest costs =	45.9
3. **Water Melon** Year		
cultivation (4), includes 1 by hand		38.3
seed	(0.3 kg x SL 46)	13.8
hand planting		7.5
fertilizer:	(3.5 kg N x SL 1.8)	6.3
	(4.8 kg phosphate x SL 2.17)	10.4
	hand broadcasting	2.5
harvest		6.3
transportation		19.2
	total cost of water melons =	104.3

B. Average Annual Cost of Three-Year Rotation:
(wheat costs + vetch estab. costs + water melon costs)/3
(SL 98 + SL 51.4 + SL 104.3)/3 = **SL 84.5/du/year**

C. Average Yields:

	Yield/du/3 years	Yield/du/year
wheat grain	223.8 kg DM	74.60 kg DM
wheat straw	97.0 kg DM	32.33 kg DM
wheat stubble	114.8 kg DM	38.3 kg DM
vetch pasture	338.3 kg DM	112.77 kg DM
or vetch hay	203.0 kg DM	67.67 kg DM
and vetch stubble	84.6 kg DM	28.20 kg DM
watermelons	415.6 kg Fresh	0.139 mt

as is the case following the mechanized harvest of a vetch hay crop. While barley and wheat crops provide grain, straw and stubble, lentil crops yield grain and straw only, and vetch provides the options of spring grazing or hay harvesting and stubble grazing.

Straw biomass was estimated according to assumed harvest indicies of 41 and 47 for barley and wheat, respectively. Amounts of cereal straw collected (Tables 1 to 4) were estimated as a function of grain yield (Nordblom, forthcoming). Only 75% of the remaining cereal stubble was assumed available to sheep since closer grazing would lead to undernutrition.

Hay production from vetch involves losses since the crop has thick stems and needs considerable drying and handling before it can be stored (Rihawi, et al, 1987). Thus, grazing of the crop in spring yields more consumable dry matter than when the crop is harvested for hay and the stubble grazed. However, the hay is a valuable feed for use in winter when it may replace more expensive feeds. The trade-offs facing the farmer in the decisions on how and when to use a vetch crop are incorporated in the whole-farm LP model, along with the other considerations mentioned above.

All farm labor for crop and sheep activities is assumed to cost SL 30 per day in wages, and charges are made at the normal custom rates for specialized operations, such as hand-

broadcasting of seed, tractor cultivation and mechanized harvesting. In practice, unpaid family labor is generally used in farm operations in the Tel Hadya area, but hired agricultural labor is also found. A judgement was made in the present analysis to charge the farm wage rate for all labor. Thus, while labor and machine availability per se are not considered as constraints in the present analysis, their costs are counted.

Experimental Flocks:

One major aim of the research on sheep husbandry at ICARDA is to define relationships between the level of nutrition and sheep performance measured as milk yield, lamb production and cull sales. For this purpose, three experimental flocks were established in June 1981. They were subjected to low, medium and high levels of nutrition and all inputs and performance parameters were recorded. The fifth breeding cycle of the experimental flocks completed the project in 1986.

Nutrition and Performance of Ewes:

For the purpose of the present study, nutrient needs of the ewes are defined according to the four major seasons of the reproductive cycle:

1. summer: ewes non-lactating. mating season (June - Sept.),
2. fall: late pregnancy (October - December),
3. winter: lambing, early lactation (January - February),
4. spring: mid and late lactation (March - May).

Total nutrient requirements on a per head (hd) basis for each season are calculated by multiplying the daily requirements, for the particular stage of the reproductive cycle, by the number of days in that season (Table 5). The seasonal requirements are expressed as constraints with dry matter intake (in kg of DM) having an upper limit, and crude protein (in kg of CP) and metabolizable energy (in mega joules (MJ) of ME) having lower limits. The upper limits for intake are expressed as percentages of liveweight (LW).

Since high nutrient density is associated with higher costs, feed mixes are chosen which satisfy the requirements at the least cost. Thus, the constraints are used to ensure that dietary composition in each of the four seasons is sufficient to allow the specified levels of ewe productivity.

Levels of ewe performance associated with each of the three nutritional regimes are shown in Table 6. The performance parameters with greatest economic importance are milk sales, weaned lamb sales and cull ewe sales. Wool is such a minor economic product in the farming system of the area that it has been ignored in the present analysis.

It is assumed that no milk is sold in the first two months of lactation since it is all consumed by lambs. In the present analysis, lambs are assumed to be sold after weaning in March, at around two months of age, and all subsequent milk is sold. Ewes on the higher nutritional regimes have better fertility, higher milk production, faster growing lambs,

TABLE 5. Nutritional Parameters for Three Ewe Regimes

SEASON and PARAMETERS	REGIME LOW	MEDIUM	HIGH
Ewe Liveweight (LW):	40 kg	45 kg	50 kg
A. Summer (Jun, Jul, Aug, Sep)			
DM[1] upper limit: 3% of LW (kg/hd/day)	1.2	1.35	1.5
CP[2] minimum % of DM	5 %	6 %	7 %
ME[3] minimum (MJ/hd/day)	7.0	7.6	8.2
DM upper limit (100 kg/hd/120 days)	1.44	1.62	1.80
CP minimum (100 kg/hd/120 days)	0.072	0.097	0.126
ME minimum (100 MJ/hd/120 days)	8.4	9.12	9.84
B. Fall (Oct, Nov, Dec)			
DM upper limit: 4% of LW (kg/hd/day)	1.6	1.8	2.0
CP minimum % of DM	8 %	10 %	12 %
ME minimum (MJ/hd/day)	8.7	9.5	10.2
DM upper limit (100 kg/hd/90 days)	1.44	1.62	1.80
CP minimum (100 kg/hd/90 days)	0.115	0.162	0.216
ME minimum (100 MJ/hd/90 days)	7.83	8.55	9.18
C. Winter (Jan, Feb)			
DM upper limit: 5% of LW (kg/hd/day)	2.0	2.25	2.5
CP minimum % of DM	8 %	10 %	12 %
ME minimum (MJ/hd/day)	15.0	17.0	19.0
DM upper limit (100 kg/hd/60 days)	1.2	1.35	1.5
CP minimum (100 kg/hd/60 days)	0.096	0.135	0.18
ME minimum (100 MJ/hd/60 days)	9.0	10.2	11.4
D. Spring (Mar, Apr, May)			
DM upper limit: 4% of LW (kg/hd/day)	1.6	1.8	2.0
CP minimum % of DM	8 %	9 %	10 %
ME minimum (MJ/hd/day)	10.0	12.0	14.0
DM upper limit (100 kg/hd/90 days)	1.44	1.62	1.80
CP minimum (100 kg/hd/90 days)	0.115	0.145	0.18
ME minimum (100 MJ/hd/90 days)	9.0	10.8	12.6

1 DM = dry matter
2 CP = crude protein
3 ME = metabolizable energy, expressed in mega Joules (MJ)

TABLE 6. Ewe Performance Parameters Under Three Regimes

	REGIME		
	LOW	MEDIUM	HIGH
A. Milk Sales: (production beyond use by lambs)			
1. In first 2 months (Jan, Feb) all milk used by lambs	--	-	-
2. In last 3 months (Mar, Apr, May) of lactation (total kg milk/hd):	40	50	60
B. Weaned Lamb Sales (1st week in Mar):			
1. No. of lambs weaned per ewe:	0.7	0.8	0.9
2. Weaning wt. of lambs (kg/lamb):	16	18	20
3. Lamb sales per ewe (kg/ewe):	11.2	14.4	18.0
C. Cull Ewe Sales:			
1. Culls as % of opening inventory:	12	14	16
2. Wt. of cull ewes (kg/hd):	40	45	50
3. Cull sales per ewe (kg):	4.8	6.3	8.0
D. Ewe Mortality Rates:			
1. Ewe deaths as % of opening inventory:	8	6	4

lower mortality levels and higher annual cull ewe sales, the latter being due to lower mortality among ewes and their higher culling weights. The economic trade-offs between ewe nutrition and performance are key aspects of the whole-farm analysis.

Feedstuff Quality:

The main feedstuffs used in the Tel Hadya area are listed in Table 7. The crude protein and metabolizable energy values of the feedstuffs are taken from ICARDA and published results. Cottonseed cake and wheat bran have high nutrient densities and were available at subsidized prices. If no artificial upper limit were imposed on their inclusion, a diet calculated simply on least cost satisfaction of the DM, CP and ME requirements would call for unreasonably high proportions of these two feeds in the mix. Therefore, upper limits of 10% on the inclusion of each of these feedstuffs are imposed for the sake of nutritional balance.

With the exception of cottonseed cake and wheat bran, all feedstuffs shown in Table 7 can be grown on the farm. The farmer has the choice of selling his crops, feeding them in different seasons of the year and purchasing extra quantities to supplement farm production.

The present analysis assumes that stubbles of barley, wheat and vetch hay crops are only available in the four month summer period and that these feedstuffs can neither be

TABLE 7. Nutritional Parameters of Feedstuffs

Feedstuff	Crude Protein (% of DM)	Metabolizable Energy (MJ/kg DM)
Vetch Hay	12.0	8.0
Vetch Pasture (in Spring)	20.0	10.0
Barley Grain	12.0	12.8
Barley Straw	3.3	5.8
Wheat Grain	12.0	12.3
Wheat Straw	3.0	5.5
Lentil Grain	25.0	12.4
Lentil Straw	7.0	7.0
Cottonseed Cake	37.0	11.5
Wheat Bran	16.5	11.0
Grazed Stubbles after Mechanical Harvest:		
Barley Stubble	4.0	6.0
Wheat Stubble	4.0	6.0
Vetch Stubble	6.0	6.0

purchased nor sold, even though this happens in practice.

Costs and Prices of Sheep and Farm Products:

Each unit of product sales or feed purchases has a price or a cost. The prices and costs listed in Table 8 are largely based on 1985 survey results (Nordblom, forthcoming). Where survey data were not available, it was assumed that purchase costs of a given commodity are 15% higher to the farmer than the price he would get if selling the same commodity.

A replacement allowance of SL 100 is charged for each ewe counted into the flock by the LP model. In a steady-state flock, it is assumed that young replacement ewes exactly balance the numbers of ewes which die or are sold as culls each year. The replacement allowance is about one-fifth the purchase cost of a young ewe. No interest is charged on such capital investments in this analysis, and no upper limit is set on capital investments to expand the flock. In a more detailed analysis, such aspects could be considered.

Native Pasture:

Each of the three experimental flocks at Tel Hadya had access to 10 ha of unimproved native pasture. However, because these areas were not sampled until 1985, herbage availabilities assumed in this analysis are based on a new study investigating effects of phosphate fertilizer application and stocking rate on native pasture productivity (ICARDA, 1986, p299).

TABLE 8. Price and Cost Assumptions for Sales and Purchases

ITEM	SALES ACTIVITY[2]	SALES PRICE (SL)	PURCHASES[1] ACTIVITY[2]	PURCHASES[1] COST (SL)
Vetch Hay	X12=VHSALE	Ø.783/kg		
Barley Grain	X15=BGSALE	1.278/kg	X22=BGPUR	1.47/kg
Barley Straw	X16=BSSALE	Ø.539/kg	X23=BSPUR	Ø.62/kg
Wheat Grain	X17=WGSALE	1.356/kg		
Wheat Straw	X18=WSSALE	Ø.435/kg		
Lentil Grain	X19=LGSALE	1.426/kg		
Lentil Straw	X2Ø=LSSALE	Ø.783/kg	X24=LSPUR	Ø.9Ø/kg
Water Melon	X21=WMSALE	Ø.69/kg		
Cottonseed Cake			X25=CSCPFA and X26=CSCPWI	1.31/kg 1.31/kg
Wheat Bran			X27=WBPURF and X28=WBPURW	Ø.55/kg Ø.55/kg
Milk	X6Ø=MILKS	3.Ø/kg		
Lambs	X61=LAMBS	12.Ø/kg		
Ewes	X62=CULLS	8.Ø/kg	X65=EWEPUR	1ØØ/head[3]

---

1 assume purchase costs are 15% higher than sales prices

2 activity code numbers (X_i) and names are used to identify commodity sales and purchases; see Table 12, Chapter 3, for a more complete explanation of activities

3 annual replacement allowance for each ewe called into the flock is assumed to be SL 1ØØ

Both unfertilized ("unimproved") and fertilized ("improved") native pasture options are included in the analysis. The data for "improved" native pasture, which receives 25 kg of phosphate per hectare each year, must be considered with caution. The new ICARDA study on improving native pasture is continuing and more reliable data will become available for future analyses.

The options for grazing the native pasture are defined in terms of the same four seasons as used to identify the nutritional requirements of ewes. Referring to Table 9, six grazing options are specified for "unimproved" native pasture, three of which allow grazing in only one season of the year while the other three allow grazing in two seasons. The same six grazing options are defined in Table 10 for "improved" native pasture which has higher yields of available herbage. Tables 9 and 10 show the estimated dry matter yields and estimated CP and ME composition of pasture herbage under the various options. The following assumptions are made to simplify the native pasture component of the whole-farm model:

1. native pasture is available for the exclusive use of the farmer's sheep - under the traditional communal grazing situation this would not be the case since other farmers could bring their sheep to graze this land;

2. herbage offtake, expressed in kg of DM per dunnum, is the amount available to sheep during the specified

TABLE 9. Unimproved Native Pasture: Yield and Nutritive Value Under Six Grazing Options

SEASON AND PARAMETERS	OPTIONS					
	Summer only	Spring and Summer	Fall and Winter	Winter only	Winter and Spring	Spring only
A. SUMMER (Jun, Jul, Aug, Sep)						
Avail herbg (100 kg DM/du)	0.6	0.15	---	---	---	---
CP 8% of DM[1] (100 kg CP/du)	0.048	0.012	---	---	---	---
ME 8 MJ/kg DM[2] (100 MJ/du)	4.8	1.2	---	---	---	---
B. FALL (Oct, Nov, Dec)						
Avail herbg (100 kg DM/du)	---	---	0.2	---	---	---
CP 7% of DM (100 kg CP/du)	---	---	0.014	---	---	---
ME 7 MJ/kg DM (100 MJ/du)	---	---	1.4	---	---	---
C. WINTER (Jan, Feb)						
Avail herbg (100 kg DM/du)	---	---	0.2	0.3	0.2	---
CP 6% of DM (100 kg CP/du)	---	---	0.012	0.018	0.012	---
ME 6 MJ/kg DM (100 MJ/du)	---	---	1.2	1.8	1.2	---
D. SPRING (Mar, Apr, May)						
Avail herbg (100 kg DM/du)	---	0.375	---	---	0.3	0.4
CP 12% of DM(100 kg CP/du)	---	0.045	---	---	0.036	0.048
ME 10 MJ/kg DM(100 MJ/du)	---	3.75	---	---	3.0	4.0

notes:

1. content of crude protein in available herbage
2. content of metabolizable energy in available herbage

TABLE 10. Improved[1] Native Pasture: Yield and Nutritive Value Under Six Grazing Options

SEASON AND PARAMETERS	OPTIONS					
	Summer only	Spring and Summer	Fall and Winter	Winter only	Winter and Spring	Spring only
A. SUMMER (Jun, Jul, Aug, Sep)						
Avail herbg (100 kg DM/du)	1.1	0.43	---	---	---	---
CP 8% of DM (100 kg CP/du)	0.088	0.034	---	---	---	---
ME 8 MJ/kg DM (100 MJ/du)	8.8	3.44	---	---	---	---
B. FALL (Oct, Nov, Dec)						
Avail herbg (100 kg DM/du)	---	---	0.5	---	---	---
CP 7% of DM (100 kg CP/du)	---	---	0.035	---	---	---
ME 7 MJ/kg DM (100 MJ/du)	---	---	3.5	---	---	---
C. WINTER (Jan, Feb)						
Avail herbg (100 kg DM/du)	---	---	0.5	0.65	0.5	---
CP 6% of DM (100 kg CP/du)	---	---	0.03	0.039	0.03	---
ME 6 MJ/kg DM (100 MJ/du)	---	---	3.0	3.9	3.0	---
D. SPRING (Mar, Apr, May)						
Avail herbg (100 kg DM/du)	---	0.75	---	---	0.65	0.8
CP 12% of DM(100 kg CP/du)	---	0.09	---	---	0.078	0.096
ME 10 MJ/kg DM(100 MJ/du)	---	7.5	---	---	6.5	8.0

Notes:

1. improved by annual application of 25 kg P_2O_5 per ha. Costs are: SL 54.25/ha for fertilizer(SL 2.17/kg), plus SL 25/ha for hand-broadcasting. Total cost is SL 79.25/ha or SL 7.93/du.

season(s) such that grazing pressure does not lead to deterioration of the pasture over several years; and

3. the quantity and nutritive value of available herbage vary according to the season and grazing option, and whether the pasture has been improved with fertilizer.

In the course of describing the whole-farm model in the next chapter, and the sample of its results in the subsequent chapter, numerous references must be made to the bio-economic data base presented in this chapter.

CHAPTER 3. THE WHOLE-FARM LINEAR PROGRAMMING MODEL

Linear programming (LP) has become a standard tool of farm management research over the past 25 years. It is also used in commercial agriculture, most commonly in formulation of "least cost" diets for livestock and poultry. It also provides a convenient operational method to deal with whole-farm planning problems. This chapter describes the structure and details of an LP model developed to reflect the farming systems of the Tel Hadya area. A short review of LP concepts, adapted from Anderson, Dillon and Hardaker (1977), is given first. A reference list on LP theory and applications can be found in Appendix B.

In LP terms, the farm planning problem is to find optimal levels of the variables $X_1, \ldots, X_j, \ldots, X_n$, where X_j represents the level of the $_j$th farming activity. The activities define the various enterprises and actions which can be practiced on the farm, and the various ways they can be managed. The choice of activity levels is restricted by a set of m linear constraints in the form of equations or inequalities:

$$\sum_{j=1}^{n} a_{ij}X_j = b_i \qquad \sum_{j=1}^{n} a_{ij}X_j \leq b_i \qquad i = 1,2 \ldots, m$$

(equations) (inequalities)

where b_i (the right hand side) may denote the upper limit on availability of the $_i$th farm resource, such as arable land or native pasture, or may be set to zero to define a constraint

within the system; the $a_{i,j}$ terms are the technical input-output coefficients which specify the amount of the $_i$th resource required for one unit of the $_j$th activity.

An example of a constraint "equation" is the requirement that barley grain production plus purchases must equal the amounts of barley sold and fed. An example of and "inequality" constraint is the requirement that the amount of cereal stubble consumed must be less than or equal to the amount available.

These constraints are used to specify the competition and interactions between activities. An additional constraint, that each activity level (X_j) be greater than or equal to zero, is imposed since negative areas of crops or negative numbers of livestock are impossible in real world solutions.

Optimality, in LP terms, is the calculated maximization of an "objective function," subject to the constraints specified above. In the present LP model, the objective function defines whole-farm net profit and may be expressed as:

$$\text{Maximize} \quad Z = \sum_{j=1}^{n} c_j X_j$$

where: Z is whole-farm profit, and c_j is the net revenue (or cost) for each unit of the $_j$th activity.

In LP, it is assumed that $a_{i,j}$, b_i and c_j are all known constants: an assumption that is fully justified only when all the planning coefficients are known for certain. For the

sake of simplicity, the present analysis takes all the production parameters and prices from Chapter 2 as constants, even though most of the biological coefficients are means of values collected over several years and the prices are those of July - August 1985.

The basic input-output parameters of the four crop rotations, the three ewe regimes and six native pasture options, as well as prices and costs for sales and input purchases, are now placed into the structure of the LP matrix which specifies the logic of their interrelationships.

The 35 constraints defined for the model, along with their descriptions and physical units, are listed by number and code name in Table 11. These identify the rows of the LP matrix (see Table 13). Each of the 63 columns of the LP matrix represents an activity (X_j), and these are considered the building blocks of the whole-farm model. The code names, descriptions and physical units which identify the 63 activities are shown in Table 12.

The list of constraints (Table 11), activities (Table 12) and the full LP matrix (Table 13), are given in the following 11 pages. Further information and explanations on the model's structure are given in the final sections of this chapter.

TABLE 11. List of Constraints for Tel Hadya LP Analysis

Row No.	Code	Description	Units
01	SSOIL	shallow soil area available for cropping	dunnum
02	DSOIL	deep soil area available for cropping	dunnum
03	NPAST	native pasture available for grazing	dunnum
04	BGRAIN	barley grain	100 kg DM
05	BSHARV	barley straw for hand feeding	100 kg DM
06	BSGRZB	barley stubble grazable by sheep	100 kg DM
07	WGRAIN	wheat grain	100 kg DM
08	WSHARV	wheat straw for hand feeding	100 kg DM
09	WSGRZB	wheat stubble grazable by sheep	100 kg DM
10	LENTGR	lentil grain	100 kg DM
11	LSHARV	lentil straw and leaves (tibn)	100 kg DM
12	WATERM	water melon production	mt fresh
13	VETCHT	vetch production, trans. to hay or pasture	100 kg DM
14	VHAY	vetch hay production	100 kg DM
15	VSGRZB	vetch stubble grazable by sheep	100 kg DM
16	DMSUMM	DM in summer diet (Jun,Jul,Aug,Sep)	100 kg DM
17	CPSUMM	crude protein in summer	100 kg CP
18	MESUMM	metabolizable energy in summer	100 MJ ME
19	DMFALL	DM in fall diet (Oct,Nov,Dec)	100 kg DM
20	CPFALL	crude protein in fall	100 kg CP
21	MEFALL	metabolizable energy in fall	100 MJ ME
22	DMWINT	DM in winter diet (Jan,Feb)	100 kg DM
23	CPWINT	crude protein in winter	100 kg CP
24	MEWINT	metabolizable energy in winter	100 MJ ME
25	DMSPRI	DM in spring diet (Mar,Apr,May)	100 kg DM
26	CPSPRI	crude protein in spring	100 kg CP
27	MESPRI	metabolizable energy in spring	100 MJ ME
28	MILKTR	milk transfer (production to sale)	100 kg
29	LAMBTR	lamb transfer (weaning to sale)	kg Live
30	CULLTR	cull ewe transfer (culling to sale)	kg Live
31	EWETR	ewe transfer (to join flock)	head
32	CSCF	control of cotton seed cake feeding in fall	100 kg DM
33	CSCW	control of cotton seed cake feeding, winter	100 kg DM
34	WBF	control of wheat bran feeding in fall	100 kg DM
35	WBW	control of wheat bran feeding in winter	100 kg DM
36	OBJ	objective function (costs and returns)	SL

TABLE 12. Activity List for Tel Hadya LP Analysis

Col No.	Code Name	Description	Units
01	BFROT	barley/fallow rotation on shallow soil	1 dunnum
02	BVROT	barley/vetch rotation on shallow soil	1 dunnum
03	WLMROT	wheat/lentil/water melons on deep soil	1 dunnum
04	WVMROT	wheat/vetch/water melons on deep soil	1 dunnum
05	VHOPT	vetch hay option (to pasture)	100 kg DM
06	VPSPRI	vetch pasture grazing in spring	100 kg DM
07	VHSUMM	vetch hay fed in summer	100 kg DM
08	VHFALL	vetch hay fed in fall	100 kg DM
09	VHWINT	vetch hay fed in winter	100 kg DM
10	VHSPRI	vetch hay fed in spring	100 kg DM
11	VSTUBS	vetch hay stubble grazed in summer	100 kg DM
12	VHSALE	vetch hay sale	100 kg DM
13	BSTUBS	barley stubble grazed in summer	100 kg DM
14	WSTUBS	wheat stubble grazed in summer	100 kg DM
15	BGSALE	barley grain sale	100 kg DM
16	BSSALE	barley straw sale	100 kg DM
17	WGSALE	wheat grain sale	100 kg DM
18	WSSALE	wheat straw sale	100 kg DM
19	LGSALE	lentil grain sale	100 kg DM
20	LSSALE	lentil straw sale	100 kg DM
21	WMSALE	water melon sale	mt fresh
22	BGPUR	barley grain purchase	100 kg DM
23	BSPUR	barley straw purchase	100 kg DM
24	LSPUR	lentil straw purchase	100 kg DM
25	CSCPFA	cotton seed cake purch. & fed in fall	100 kg DM
26	CSCPWI	cotton seed cake purch. & fed in winter	100 kg DM
27	WBPURF	wheat bran purchased and fed in fall	100 kg DM
28	WBPURW	wheat bran purchased and fed in winter	100 kg DM
29	BGSUMM	barley grain fed in summer	100 kg DM
30	BGFALL	barley grain fed in fall	100 kg DM
31	BGWINT	barley grain fed in winter	100 kg DM
32	BGSPRI	barley grain fed in spring	100 kg DM

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TABLE 12. Activity List, continued

Col No.	Code Name	Description	Units
33	BSSUMM	barley straw fed in summer	100 kg DM
34	BSFALL	barley straw fed in fall	100 kg DM
35	BSWINT	barley straw fed in winter	100 kg DM
36	BSSPRI	barley straw fed in spring	100 kg DM
37	WGSUMM	wheat grain fed in summer	100 kg DM
38	WGFALL	wheat grain fed in fall	100 kg DM
39	WGWINT	wheat grain fed in winter	100 kg DM
40	WGSPRI	wheat grain fed in spring	100 kg DM
41	WSSUMM	wheat straw fed in summer	100 kg DM
42	WSFALL	wheat straw fed in fall	100 kg DM
43	WSWINT	wheat straw fed in winter	100 kg DM
44	WSSPRI	wheat straw fed in spring	100 kg DM
45	LGFALL	lentil grain fed in fall	100 kg DM
46	LGWINT	lentil grain fed in winter	100 kg DM
47	LGSPRI	lentil grain fed in spring	100 kg DM
48	LSFALL	lentil straw fed in fall	100 kg DM
49	LSWINT	lentil straw fed in winter	100 kg DM
50	LSSPRI	lentil straw fed in spring	100 kg DM
51	NPSUMM	native pasture grazed in summer only	1 du
52	NPSUSP	native pasture grazed in spring and summer	1 du
53	NPFAWI	native pasture grazed in fall and winter	1 du
54	NPWINT	native pasture grazed in winter only	1 du
55	NPWISP	native pasture grazed in winter and spring	1 du
56	NPSPRI	native pasture grazed in spring only	1 du
57	LMEWE	ewe on low nutritional regime	head
58	MMEWE	ewe on medium nutritional regime	head
59	MHEWE	ewe on high nutritional regime	head
60	MILKS	milk sales activity	100 kg milk
61	LAMBS	lamb sales activity	kg live wt.
62	CULLS	cull ewe sales activity	kg live wt.
63	EWEPUR	ewe investment activity	head

****

64	RIGHT HAND SIDE (RHS): resource limits	constraint units

TABLE 13.1 Tel Hadya LP Matrix: page 1 of 8 pages

Row No.	ACTIVITY: Code	X1 BFROT	X2 BVROT	X3 WLMROT	X4 WVMROT	X5 VHOPT	X6 VPSPRI	X7 VHSUMM	X8 VHFALL
	Units:	1 du	1 du	1 du	1 du	100 kg DM	100 kg DM	100 kg DM	100 kg DM
01	SSOIL	1.0	1.0	.	.	.	.	.	.
02	DSOIL	.	.	1.0	1.0	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	0.636	1.099	.		.	.	.	.
05	BSHARV	-0.34	-0.478	.	.	.	.	.	.
06	BSGRZB	0.446	0.859	.	.	.	.	.	.
07	WGRAIN	.	.	0.571	-0.746	.	.	.	.
08	WSHARV	.	.	-0.268	-0.323	.	.	.	.
09	WSGRZB	.	.	-0.278	-0.383	.	.	.	.
10	LENTGR	.	.	-0.254	.	.	.	.	.
11	LSHARV	.	.	-0.431	.	.	.	.	.
12	WATERM	.	.	-0.132	-0.139	.	.	.	.
13	VETCHT	.	-1.25	.	-1.128	1.0	1.0	.	.
14	VHAY	.	.	.	.	-0.6	.	1.0	1.0
15	VSGRZB	.	.	.	.	-0.25	.	.	.
16	DMSUMM	.	.	.	.	.	.	1.0	.
17	CPSUMM	.	.	.	.	.	.	-0.12	.
18	MESUMM	.	.	.	.	.	.	-8.0	.
19	DMFALL	.	.	.	.	.	.	.	1.0
20	CPFALL	.	.	.	.	.	.	.	-0.12
21	MEFALL	.	.	.	.	.	.	.	-8.0
22	DMWINT	.	.	.	.	.	.	.	.
23	CPWINT	.	.	.	.	.	.	.	.
24	MEWINT	.	.	.	.	.	.	.	.
25	DMSPRI	.	.	.	.	.	1.0	.	.
26	CPSPRI	.	.	.	.	.	-0.2	.	.
27	MESPRI	.	.	.	.	.	-10.0	.	.
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	-41.8	-74.2	-121.4	-84.5	-13.6	0	0	0

TABLE 13.2 **Tel Hadya LP Matrix**: page 2 of 8 pages

ACTIVITY:		X9	X10	X11	X12	X13	X14	X15	X16
	Units:	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM
Row No.	Code	VHWINT	VHSPRI	VSTUBS	VHSALE	BSTUBS	WSTUBS	BGSALE	BSSALE
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	.	.	.	.	.	.	1.0	.
05	BSHARV	.	.	.	.	.	.	.	1.0
06	BSGRZB	.	.	.	.	1.0	.	.	.
07	WGRAIN	.	.	.	.	.	.	.	.
08	WSHARV	.	.	.	.	.	.	.	.
09	WSGRZB	.	.	.	.	.	1.0	.	.
10	LENTGR	.	.	.	.	.	.	.	.
11	LSHARV	.	.	.	.	.	.	.	.
12	WATERM	.	.	.	.	.	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	1.0	1.0	.	1.0	.	.	.	.
15	VSGRZB	.	.	1.0	.	.	.	.	.
16	DMSUMM	.	.	1.0	.	1.0	1.0	.	.
17	CPSUMM	.	.	-0.06	.	-0.04	-0.04	.	.
18	MESUMM	.	.	-6.0	.	-6.0	-6.0	.	.
19	DMFALL	.	.	.	.	.	.	.	.
20	CPFALL	.	.	.	.	.	.	.	.
21	MEFALL	.	.	.	.	.	.	.	.
22	DMWINT	1.0	.	.	.	.	.	.	.
23	CPWINT	-0.12	.	.	.	.	.	.	.
24	MEWINT	-8.0	.	.	.	.	.	.	.
25	DMSPRI	.	1.0	.	.	.	.	.	.
26	CPSPRI	.	-0.12	.	.	.	.	.	.
27	MESPRI	.	-8.0	.	.	.	.	.	.
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	0	0	0	78.3	0	0	127.8	53.9

TABLE 13.3 Tel Hadya LP Matrix: page 3 of 8 pages

ACTIVITIES:		X17	X18	X19	X20	X21	X22	X23	X24
	Units:	100 kg DM	100 kg DM	100 kg DM	100 kg DM	mt. fresh	100 kg DM	100 kg DM	100 kg DM
Row No.	Code	WGSALE	WSSALE	LGSALE	LSSALE	WMSALE	BGPUR	BSPUR	LSPUR
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	.	.	.	.	.	-1.0	.	.
05	BSHARV	.	.	.	.	.	.	-1.0	.
06	BSGRZB	.	.	.	.	.	.	.	.
07	WGRAIN	1.0	.	.	.	.	.	.	.
08	WSHARV	.	1.0	.	.	.	.	.	.
09	WSGRZB	.	.	.	.	.	.	.	.
10	LENTGR	.	.	1.0	.	.	.	.	.
11	LSHARV	.	.	.	1.0	.	.	.	-1.0
12	WATERM	.	.	.	.	1.0	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	.	.	.	.	.	.	.	.
15	VSGRZB	.	.	.	.	.	.	.	.
16	DMSUMM	.	.	.	.	.	.	.	.
17	CPSUMM	.	.	.	.	.	.	.	.
18	MESUMM	.	.	.	.	.	.	.	.
19	DMFALL	.	.	.	.	.	.	.	.
20	CPFALL	.	.	.	.	.	.	.	.
21	MEFALL	.	.	.	.	.	.	.	.
22	DMWINT	.	.	.	.	.	.	.	.
23	CPWINT	.	.	.	.	.	.	.	.
24	MEWINT	.	.	.	.	.	.	.	.
25	DMSPRI	.	.	.	.	.	.	.	.
26	CPSPRI	.	.	.	.	.	.	.	.
27	MESPRI	.	.	.	.	.	.	.	.
28	MJLKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	135.6	43.5	142.6	78.3	690.0	-147.0	-62.0	-90.0

TABLE 13.4 Tel Hadya LP Matrix: page 4 of 8 pages

ACTIVITIES:		X25	X26	X27	X28	X29	X30	X31	X32
	Units:	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM
Row No.	Code	CSCPFA	CSCPWI	WBPURF	WBPURW	BGSUMM	BGFALL	BGWINT	BGSPRI
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	.	.	.	.	1.0	1.0	1.0	1.0
05	BSHARV	.	.	.	.	.	.	.	.
06	BSGRZB	.	.	.	.	.	.	.	.
07	WGRAIN	.	.	.	.	.	.	.	.
08	WSHARV	.	.	.	.	.	.	.	.
09	WSGRZB	.	.	.	.	.	.	.	.
10	LENTGR	.	.	.	.	.	.	.	.
11	LSHARV	.	.	.	.	.	.	.	.
12	WATERM	.	.	.	.	.	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	.	.	.	.	.	.	.	.
15	VSGRZB	.	.	.	.	.	.	.	.
16	DMSUMM	.	.	.	.	1.0	.	.	.
17	CPSUMM	.	.	.	.	-0.12	.	.	.
18	MESUMM	.	.	.	.	-12.8	.	.	.
19	DMFALL	1.0	.	1.0	.	.	1.0	.	.
20	CPFALL	-0.37	.	-0.165	.	.	-0.12	.	.
21	MEFALL	-11.5	.	-11.0	.	.	-12.8	.	.
22	DMWINT	.	1.0	.	1.0	.	.	1.0	.
23	CPWINT	.	-0.37	.	-0.165	.	.	-0.12	.
24	MEWINT	.	-11.5	.	-11.0	.	.	-12.[illegible]	.
25	DMSPRI	.	.	.	.	.	.	.	1.0
26	CPSPRI	.	.	.	.	.	.	.	-0.12
27	MESPRI	.	.	.	.	.	.	.	-12.8
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	1.0	.	.	.	.	.	.	.
33	CSCW	.	1.0	.	.	.	.	.	.
34	WBF	.	.	1.0	.	.	.	.	.
35	WBW	.	.	.	1.0	.	.	.	.
36	OBJ	-131.0	-131.0	-55.0	-55.0	0	0	0	0

TABLE 13.5 Tel Hadya LP Matrix: page 5 of 8 pages

Row No.	ACTIVITIES: Code	X33 BSSUMM	X34 BSFALL	X35 BSWINT	X36 BSSPRI	X37 WGSUMM	X38 WGFALL	X39 WGWINT	X40 WGSPRI
	Units:	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	.	.	.	.	.	.	.	.
05	BSHARV	1.0	1.0	1.0	1.0	.	.	.	.
06	BSGRZB	.	.	.	.	.	.	.	.
07	WGRAIN	.	.	.	.	1.0	1.0	1.0	1.0
08	WSHARV	.	.	.	.	.	.	.	.
09	WSGRZB	.	.	.	.	.	.	.	.
10	LENTGR	.	.	.	.	.	.	.	.
11	LSHARV	.	.	.	.	.	.	.	.
12	WATERM	.	.	.	.	.	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	.	.	.	.	.	.	.	.
15	VSGRZB	.	.	.	.	.	.	.	.
16	DMSUMM	1.0	.	.	.	1.0	.	.	.
17	CPSUMM	-0.033	.	.	.	-0.12	.	.	.
18	MESUMM	-5.8	.	.	.	-12.3	.	.	.
19	DMFALL	.	1.0	.	.	.	1.0	.	.
20	CPFALL	.	-0.033	.	.	.	-0.12	.	.
21	MEFALL	.	-5.8	.	.	.	-12.3	.	.
22	DMWINT	.	.	1.0	.	.	.	1.0	.
23	CPWINT	.	.	-0.033	.	.	.	-0.12	.
24	MEWINT	.	.	-5.8	.	.	.	-12.3	.
25	DMSPRI	.	.	.	1.0	.	.	.	1.0
26	CPSPRI	.	.	.	-0.033	.	.	.	-0.12
27	MESPRI	.	.	.	-5.8	.	.	.	-12.3
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	0	0	0	0	0	0	0	0

TABLE 13.6 **Tel Hadya LP Matrix**: page 6 of 8 pages

Row No.	Code	X41	X42	X43	X44	X45	X46	X47	X48
	Units:	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM	100 kg DM
		WSSUMM	WSFALL	WSWINT	WSSPRI	LGFALL	LGWINT	LGSPRI	LSFALL
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	.	.	.	.	.	.
04	BGRAIN	.	.	.	.	.	.	.	.
05	BSHARV	.	.	.	.	.	.	.	.
06	BSGRZB	.	.	.	.	.	.	.	.
07	WGRAIN	.	.	.	.	.	.	.	.
08	WSHARV	1.0	1.0	1.0	1.0	.	.	.	.
09	WSGRZB	.	.	.	.	.	.	.	.
10	LENTGR	.	.	.	.	1.0	1.0	1.0	.
11	LSHARV	.	.	.	.	.	.	.	1.0
12	WATERM	.	.	.	.	.	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	.	.	.	.	.	.	.	.
15	VSGRZB	.	.	.	.	.	.	.	.
16	DMSUMM	1.0	.	.	.	.	.	.	.
17	CPSUMM	-0.03	.	.	.	.	.	.	.
18	MESUMM	-5.5	.	.	.	.	.	.	.
19	DMFALL	.	1.0	.	.	1.0	.	.	1.0
20	CPFALL	.	-0.03	.	.	-0.25	.	.	-0.07
21	MEFALL	.	-5.5	.	.	-12.4	.	.	-7.0
22	DMWINT	.	.	1.0	.	.	1.0	.	.
23	CPWINT	.	.	-0.03	.	.	-0.25	.	.
24	MEWINT	.	.	-5.5	.	.	-12.4	.	.
25	DMSPRI	.	.	.	1.0	.	.	1.0	.
26	CPSPRI	.	.	.	-0.03	.	.	-0.25	.
27	MESPRI	.	.	.	-5.5	.	.	-12.4	.
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	0	0	0	0	0	0	0	0

TABLE 13.7 Tel Hadya LP Matrix: page 7 of 8 pages

ACTIVITIES:		X49	X50	X51	X52	X53	X54	X55	X56
	Units:	100 kg DM	100 kg DM	1 du	1 du	1 du	1 du	1 du	1 du
Row No.	Code	LSWINT	LSSPRI	NPSUMM	NPSUSP	NPFAWI	NPWINT	NPWISP	NPSPRI
01	SSOIL	.	.	.	.	.	.	.	.
02	DSOIL	.	.	.	.	.	.	.	.
03	NPAST	.	.	1.0	1.0	1.0	1.0	1.0	1.0
04	BGRAIN	.	.	.	.	.	.	.	.
05	BSHARV	.	.	.	.	.	.	.	.
06	BSGRZB	.	.	.	.	.	.	.	.
07	WGRAIN	.	.	.	.	.	.	.	.
08	WSHARV	.	.	.	.	.	.	.	.
09	WSGRZB	.	.	.	.	.	.	.	.
10	LFNTGR	.	.	.	.	.	.	.	.
11	LSHARV	1.0	1.0	.	.	.	.	.	.
12	WATERM	.	.	.	.	.	.	.	.
13	VETCHT	.	.	.	.	.	.	.	.
14	VHAY	.	.	.	.	.	.	.	.
15	VSGRZB	.	.	.	.	.	.	.	.
16	DMSUMM	.	.	0.6	0.15	.	.	.	.
17	CPSUMM	.	.	-0.048	-0.012	.	.	.	.
18	MESUMM	.	.	-4.8	-1.2	.	.	.	.
19	DMFALL	.	.	.	.	0.2	.	.	.
20	CPFALL	.	.	.	.	-0.014	.	.	.
21	MEFALL	.	.	.	.	-1.4	.	.	.
22	DMWINT	1.0	.	.	.	0.2	0.3	0.2	.
23	CPWINT	-0.07	.	.	.	-0.012	-0.018	-0.012	.
24	MEWINT	-7.0	.	.	.	-1.2	-1.8	-1.2	.
25	DMSPRI	.	1.0	.	0.375	.	.	0.3	0.4
26	CPSPRI	.	-0.07	.	-0.045	.	.	-0.036	-0.048
27	MESPRI	.	-7.0	.	-3.75	.	.	-3.0	-4.0
28	MILKTR	.	.	.	.	.	.	.	.
29	LAMBTR	.	.	.	.	.	.	.	.
30	CULLTR	.	.	.	.	.	.	.	.
31	EWETR	.	.	.	.	.	.	.	.
32	CSCF	.	.	.	.	.	.	.	.
33	CSCW	.	.	.	.	.	.	.	.
34	WBF	.	.	.	.	.	.	.	.
35	WBW	.	.	.	.	.	.	.	.
36	OBJ	0	0	0	0	0	0	0	0

TABLE 13.8 Tel Hadya LP Matrix: page 8 of 8 pages

ACTIVITIES:		X57	X58	X59	X60	X61	X62	X63	X64
	Units:	head	head	head	100 kg milk	kg L.W.	kg L.W.	head	
Row No.	Code	LMEWE	MMEWE	MHEWE	MILKS	LAMBS	CULLS	EWEPUR	RHS
01	SSOIL	.	.	.	.	.	.	.	≤ 100
02	DSOIL	.	.	.	.	.	.	.	≤ 0
03	NPAST	.	.	.	.	.	.	.	≤ 100
04	BGRAIN	.	.	.	.	.	.	.	= 0
05	BSHARV	.	.	.	.	.	.	.	= 0
06	BSGRZB	.	.	.	.	.	.	.	≤ 0
07	WGRAIN	.	.	.	.	.	.	.	= 0
08	WSHARV	.	.	.	.	.	.	.	= 0
09	WSGRZB	.	.	.	.	.	.	.	≤ 0
10	LENTGR	.	.	.	.	.	.	.	= 0
11	LSHARV	.	.	.	.	.	.	.	= 0
12	WATERM	.	.	.	.	.	.	.	= 0
13	VETCHT	.	.	.	.	.	.	.	= 0
14	VHAY	.	.	.	.	.	.	.	= 0
15	VSGRZB	.	.	.	.	.	.	.	≤ 0
16	DMSUMM	-1.44	-1.62	-1.8	.	.	.	.	≤ 0
17	CPSUMM	0.072	0.097	0.126	.	.	.	.	≤ 0
18	MESUMM	8.4	9.12	9.84	.	.	.	.	≤ 0
19	DMFALL	-1.44	-1.62	-1.8	.	.	.	.	≤ 0
20	CPFALL	0.115	0.162	0.216	.	.	.	.	≤ 0
21	MEFALL	7.83	8.55	9.18	.	.	.	.	≤ 0
22	DMWINT	-1.2	-1.35	-1.5	.	.	.	.	≤ 0
23	CPWINT	0.096	0.135	0.18	.	.	.	.	≤ 0
24	MEWINT	9.0	10.2	11.4	.	.	.	.	≤ 0
25	DMSPRI	-1.44	-1.62	-1.8	.	.	.	.	≤ 0
26	CPSPRI	0.115	0.145	0.18	.	.	.	.	≤ 0
27	MESPRI	9.0	10.8	12.6	.	.	.	.	≤ 0
28	MILKTR	0.4	0.5	0.6	-1.0	.	.	.	= 0
29	LAMBTR	11.2	14.4	18.0	.	-1.0	.	.	= 0
30	CULLTR	4.8	6.3	8.0	.	.	-1.0	.	= 0
31	EWETR	1.0	1.0	1.0	.	.	.	-1.0	= 0
32	CSCF	-0.144	-0.162	-0.180	.	.	.	.	≤ 0
33	CSCW	-0.120	-0.135	-0.150	.	.	.	.	≤ 0
34	WBF	-0.144	-0.162	-0.180	.	.	.	.	≤ 0
35	WBW	-0.120	-0.135	-0.150	.	.	.	.	≤ 0
36	OBJ	-40.0	-50.0	-60.0	300.0	12.0	8.0	-100.0	MAXIMIZE

The Constraints:

The first constraint in the LP matrix (see Tables 11 and 13) limits the the availability of land with shallow soil (SSOIL) to a predetermined level. The total of the land areas used for the barley-fallow rotation, shown in column X1 of Table 13 as BFROT, and the barley vetch rotation, shown in column X2 as BVROT, is constrained to be less than or equal to the area of shallow soil available. Hence the function:

$$a_{1,1} X_1 + a_{1,2} X_2 \leq b_1 \quad \text{or} \quad BFROT + BVROT \leq SSOIL$$

Similarly, the constraint shown in row 2, DSOIL, limits the amount of land available for the two deep-soil rotations, wheat-lentil-melon, shown as WLMROT in column X3, and wheat-vetch-melon, shown as WVMROT in column X4. The sum of the land areas used for the two deep-soil rotations is constrained to be less than or equal to the area of deep soil available. This gives the constraint function:

$$a_{2,3} X_3 + a_{2,4} X_4 \leq b_2 \quad \text{or} \quad WLMROT + WVMROT \leq DSOIL$$

Constraint row 3, NPAST, limits the use of native pasture for grazing to an amount less than or equal to the amount available. Thus, the six grazing options for native pasture (Tables 9 and 10) may only be chosen in combinations where the total area grazed is less than or equal to the area of native pasture available. This can be expressed as:

$$X_{51} + X_{52} + X_{53} + X_{54} + X_{55} + X_{56} \leq b_3$$

or

$$NPSUMM + NPSUSP + NPFAWI + NPWINT + NPWISP + NPSPRI \leq NPAST$$

The fourth constraint, BGRAIN, ensures that the sum of the barley produced on the farm and purchased is exactly equal to the sum of the amounts fed and sold. This constraint may be expressed as the following linear equation:

$$-.636X_1 - 1.099X_2 + X_{15} - X_{22} + X_{29} + X_{30} + X_{31} + X_{32} = b_4 = 0$$

Similarly, the fifth constraint, BSHARV, balances the amounts of barley straw produced and purchased against the amounts fed and sold. Constraint six, BSGRZB, requires the amount of barley stubble grazed to be less than or equal to the amount available on the farm after the harvest of the barley crop.

Constraints seven (WGRAIN), eight (WSHARV) and nine (WSGRZB) control the disposition of wheat crops in the same manner as those mentioned above for barley crops. Constraints ten (LENTGR) and eleven (LSHARV) control the disposition of the lentil crop similarly, except that the lack of lentil stubble for grazing means there is no need for a constraint on its use. Constraint LSHARV allows purchase and feeding of lentil straw even when this crop is not grown on the farm. Constraint twelve (WATERM) ensures that all the water melons produced on the farm are sold.

The thirteenth constraint (VETCHT) ensures that vetch crops are either grazed in spring or used for hay production. The fourteenth constraint (VHAY) ensures that all vetch hay which is produced will either be fed on the farm or be sold. Constraint fifteen (VSGRZB) restricts the grazable quantity of vetch stubble following a hay crop to less than or equal

the amount available.

Next come four groups of feeding constraints, one group for each of the four seasons of the sheep reproductive cycle (summer, fall, winter and spring) as shown in Table 5. The summer feed constraints, DMSUMM, CPSUMM and MESUMM, shown in rows 16, 17 and 18, ensure that the nutritional requirements of the ewes are met during this season. The DMSUMM constraint guarantees the upper limits on dry matter intake are not exceeded, whereas the CPSUMM and MESUMM constraints ensure adequate dietary levels of crude protein and metabolizable energy in the summer diets.

The fall, winter and spring feed constraints, shown in rows 19 to 27, operate to satisfy the dietary requirements given in Table 5 in the same manner as those for summer. Taken together, the four groups of feeding constraints guarantee that nutritionally adequate diets are available throughout the year for the number of ewes in the LP solution.

Constraint rows 28 to 31 account for the physical transfer of commodities from one status to another. Thus, the constraint MILKTR ensures that all milk produced for sale in spring is transfered to the "milk sales" activity. The constraint LAMBTR ensures that all lambs are sold. The cull ewe transfer constraint, CULLTR, allocates a given liveweight to the "cull sales" activity for each ewe in the flock. Finally, a ewe transfer constraint, EWETR, permits a replacement allowance to be charged for each ewe.

The final four constraints, 32 to 35, impose the upper limits on proportions of cottonseed cake and wheat bran in the fall and winter diets of ewes. Reasons for this were discussed briefly in Chapter 2; individually, these feedstuffs cannot contrbute more than 10% of the maximum dry matter intake in either season. Thus, such practical "rule-of-thumb" limitations are easily included in the structure of an LP model.

The last row in the LP matrix is known as the "objective function." This row contains the costs and prices which guide the solution of the LP model to find that combination of activities which is "best:" that is, the profit (sales minus costs) maximizing combination of activities within the set of constraints defined above.

The Activities:

This section discusses the components of the farming system in terms of the activities, or X_j variables, in the LP matrix (Table 13). The code names, descriptions and physical units of the activities are shown in Table 12. This section also aims to clarify the interactions and interdependencies among the 63 activities which can be divided into several groups for this purpose: crop production and sales activities, feed purchase and feeding activities, native pasture activities, and ewe management and sales activities.

Crop Production and Sales:

The first four activities, shown in columns X1 to X4 of the LP matrix, represent the four crop rotations which were defined in Tables 1 to 4. Reading down the first column (X1), which represents the barley-fallow rotation (BFROT), one sees that a unit of this activity requires one dunnum of shallow soil and that this land is expected to produce 63.6 kg of barley grain, 34.0 kg of harvested straw and 44.6 kg of grazable stubble, averaged over the crop and fallow years. The average annual cost, SL 41.8, is shown in the objective function, row 36. These yield and cost data were derived in Table 1. The reason some coefficients are negative and others positive within constraint rows is that these must balance to produce the desired upper and lower limits.

The next three columns, X2, X3 and X4, show the various resource requirements, crop yields and costs of the other

three rotations, as derived in Tables 2, 3 and 4.

The fifth activity, VHOPT, represents the option to produce vetch hay in competition with the next activity, VPSPRI, grazing the vetch crop as spring pasture. In order to satisfy the constraint in row 13 (VETCHT), the vetch crop must either be used for hay production or for grazing. The objective row coefficient of the VHOPT activity is the estimated costs of harvesting and storing 60 kg of vetch hay DM, leaving 25 kg of grazable stubble. These figures allow for losses in the hay making process and during stubble grazing. The other alternative is grazing the 100 kg of herbage DM in spring, using the VPSPRI activity (X6). instead. The cost of the hay option, SL 13.6 in the objective row, represents only harvest, handling and transport costs for the 60 kg of hay. Other costs of producing vetch are included in the objective coefficients of the two rotations which involve vetch crops: barley-vetch (X2) and wheat-vetch-melon (X4).

The three coefficients shown in column X6 and rows 25, 26 and 27 of the matrix represent the amounts of DM, CP and ME provided by one unit of the VPSPRI activity. This vetch pasture is only available for grazing in spring, a consideration which must be weighed against the more flexible but expensive alternative of harvesting the crop as hay which can be fed at any time of the year.

The next four activities, X7 to X10, represent the feeding of

vetch hay in summer, fall, winter and spring, respectively. The DM, CP and ME coefficients are identical for each of these activities, but their positions in the constraint rows of the matrix differ according to the season of the year in which they are used.

Vetch stubble (activity X11, VSTUBS) only provides grazing in summer, and only when a vetch crop has been harvested for hay. The sale of vetch hay (activity X12, VHSALE) reduces the supply of hay for the farmer's own flock, but generates an income of SL 78.3 per 100 kg of hay sold. It is assumed that grazing of barley and wheat stubbles (activities X13 and X14, BSTUBS and WSTUBS) may only take place in summer.

Next in the matrix are seven crop sales activities, from barley grain sales (activity X15, BGSALE) through water melon sales (activity X21, WMSALE). Each of these activities produces income and, therefore, has a positive coefficient in the objective row. They each also have a single coefficient in their respective crop constraint rows.

Feed Purchase and Feeding Activities:

A considerable portion of the matrix (columns X22 to X50) is needed to describe the various feeding activities in terms of sources of material, nutritive value and timing. The nutritive value parameters for each feedstuff are taken from Table 7. Details on the special characteristics of the several feedstuff groups are given below.

The three columns, X22, X23 and X24, represent activities which allow the purchase of barley grain (BGPUR), barley straw (BSPUR) and lentil straw (LSPUR) to supplement such feedstuffs grown on the farm. Their purchase costs are indicated in the objective row.

Activities X25 to X28 (CSCPFA, CSCPWI, WBPURF and WBPURW) allow purchase and feeding of cottonseed cake and wheat bran during fall and winter. Their coefficients in constraint rows 32 to 35 are balanced against limitations of the ewe activities (X57 to X59) to prevent inclusion of either of these feeds at levels greater than 10% of the maximum fall or winter diets.

Columns X29 to X32 (BGSUMM, BGFALL, BGWINT and BGSPRI) represent the barley grain feeding activities in summer, fall, winter and spring, respectively. Their coefficients in constraint row 4 (BGRAIN) are used to balance these feeding activities against barley production, purchases and sales.

Columns X33 to X44 represent the feeding activities for barley straw, wheat grain and wheat straw for each of the four seasons of the year. The structures of these activities are similar to those for barley grain. In the cases of wheat grain and straw no supplementary purchase activities are permitted in the model. Thus, for these commodities, only a balance between production, sales and feeding activities is required.

Columns X45, X46 and X47 represent the feeding activities for lentil grain in the fall, winter and spring seasons, respectively. No lentil grain purchase activity is defined in the model. Columns X48, X49 and X50 identify lentil straw feeding activities for the same three seasons. The sources of lentil straw may be the farm's own wheat-lentil-melon rotation or purchases.

Native Pasture Grazing Activities:

Columns X51 to X56 define the six grazing options shown in Table 9. Each unit of one of these activities requires one dunnum of native pasture land, hence the coefficients in constraint row 3. As with the feeding activities, these grazing options define specific quantities and nutritive values of available herbage for each of the four seasons.

For example, when native pasture is grazed only in summer, 60 kg of herbage DM per dunnum is available to the sheep (see row 16 in column X51, NPSUMM). This quantity of mature dry herbage contains 4.8 kg crude protein and 480 MJ of metabolizable energy (rows 17 and 18). The option to graze the pasture in both winter and spring (column X55, NPWISP) may be preferred since this would substitute for conserved or purchased feeds. The trade-offs involved in selecting a grazing option will include considerations of the quantities and nutritive values of available herbage, in addition to the costs and availabilities of other feedstuffs in all other seasons of the year.

For LP solutions which include consideration of "improved" (fertilized) native pasture, all the coefficients in rows 16 to 27, for columns X51 to X56, are replaced with the values in Table 10. Costs of fertilization for improved native pasture activities would be indicated in the objective row.

Ewe Management and Milk, Lamb and Cull Sales Activities:

Apart from water melon sales (activity column X21), all of the 56 activities described up to this point are concerned with sources and allocations of feeds and pastures for sheep. This illustrates the key role played by sheep as a channel for marketing the farm's crop and pasture production.

Three ewe management activities with different nutritional regimes and performance levels (low, medium and high) are identified in columns X57, X58 and X59. The coefficients in the feed constraint rows are taken from Table 5. The dry matter coefficients for these three activities each have negative signs (see rows 16, 19, 22, 25 and 32 to 35) which are balanced against the positive coefficients of the feeding activities in the same rows. This ensures that the upper limits on dry matter intake are not exceeded since, within each of these rows, the sum of the activity levels multiplied by their respective coefficients is constrained to be less than or equal to zero.

The constraints on cottonseed cake and wheat bran intake for the three ewe activities (shown in rows 32 to 35, set upper

limits on the inclusion of these feedstuffs in the fall and winter diets to 10% of the maximum dry matter intake levels.

Positive coefficients for the CP and ME requirements have been specified for each of the ewe activities in each season, while all coefficients for these two characteristics among the feeding activities are negative. Requiring the sum of products in each CP and ME row to be less than or equal to zero ensures that the ewes receive no less than their lower dietary limits of protein and energy.

The costs shown in the objective row for the three ewe activities reflect the annual labor for feeding and handling and have been set in exact proportion to milk production per head.

The performance coefficients in rows 28 to 30 for the three ewe activities are taken from Table 6. These three rows have been defined as "transfer" equations such that:

1. total milk sales (activity column X60) equals milk production in spring,

2. total weight of lambs sold (activity X61) equals the total weight of all lambs weaned,

3. the total weight of cull ewe sales (activity X62) equals the total weight of ewes culled.

The prices of milk, lambs and culls are shown in the objective row for these sales activities.

Each ewe called into the LP solution is assumed to cost the farmer SL 100 in annual replacement allowances. This is shown in the objective row of activity X63, EWEPUR.

The Right Hand Side:

This chapter concludes with the subject of internal and external resource limitations. The reasons that constraints in the LP model are mathematically specified as equations or inequalities should be clear by now. The final column, X64, represents the "right-hand-side" (RHS) of the equations and inequalities which comprise the 35 constraint rows in the model. These specify limits on the resources available in a solution of the model when a particular question is investigated.

The RHS of rows 1 and 3 in the matrix put upper limits of 100 dunnums (10 ha) on the areas of both arable land with shallow soil and native pasture. Such non-zero values on the RHS indicate limits outside the relationships defined within the body of the matrix. Zero values on the RHS indicate constraints which must balance within the matrix. Examples are: water melon sales must equal the amount produced, and the amount of cereal stubble grazed must be less than or equal to the amount available.

The whole-farm LP model in Table 13 comprises 63 activity columns for which an "optimum" combination is to be

mathematically determined which will maximize the objective function (profit = sales minus costs) in row 36, subject to the 35 constraints and their RHS values. Examples given in the following chapter show that this model provides a powerful analytical framework for answering questions of bio-economic balance in farming systems found in the Tel Hadya area.

CHAPTER 4. RESULTS

Resource and Management Scenarios:

Farms in the Tel Hadya area vary in size and other resource parameters such as soil types and pasture availability; thus, the optimal combination of activities will vary from farm to farm. Also, for a given farm, a new set of prices and costs can mean a new optimal combination of activities. Different optimal solutions will be found under different sets of resource constraints and prices. This means the possibilities for different solutions are virtually infinite. In the sample of results presented here for the whole-farm LP model, the picture is simplified by using only one set of prices and is further restricted to consider only a few combinations of arable land and native pasture availability.

Thirty-six scenarios are presented in this chapter, each showing a different optimal solution under a different set of resource constraints and management choices. These are aimed to serve as practical examples of how to use the whole-farm LP model. They also present, for the first time, a whole-farm analysis of the farming system in the Tel Hadya area. The 36 scenarios are identified in Table 14.

A common feature of all 36 scenarios is that each considers a farm with 100 dunnums (10 ha) of arable land. Half, eighteen, of the scenarios consider farms with shallow soil and the other half, farms with deep soil. Within each of

TABLE 14. Identification of Resource and Management Scenarios

	Native Pasture Availability								
	None			10 ha Unimproved (unfertilized)			10 ha Improved (fertilized)		
Ewe regime:	Low	Med	High	Low	Med	High	Low	Med	High
Arable land & Rotation									
10 ha shallow soil									
BARLEY-FALLOW	1[a/]	2	3	4	5	6	7	8	9
BARLEY-VETCH	10	11	12	13	14	15	16	17	18
10 ha Deep Soil									
WHEAT-LENTIL-MELON	19	20	21	22	23	24	25	26	27
WHEAT-VETCH-MELON	28	29	30	31	32	33	34	35	36

a/ scenario number

these soil categories, half of the scenarios consider crop management under traditional rotations and half under high-input rotations. Thus, each of the four crop rotations are represented by nine scenarios: the barley-fallow rotation by scenarios 1 - 9, the barley-vetch rotation by scenarios 10 - 18, the wheat-lentil-melon rotation by scenarios 19 - 27, and the wheat-vetch-melon rotation by scenarios 28 - 36.

The nine scenarios for each crop rotation are divided into three groups which identify different levels of available grazing from native pasture. The first of these groups considers that no native pasture is available to supplement the 10 ha of arable farmland. An unimproved native pasture area of 10 ha is considered available for grazing in the second group. An identical area of improved pasture characterizes the third group. The herbage availability from such pastures was discussed earlier in connection with Tables 9 and 10. A final subdivision of the scenarios distinguishes three nutritional regimes for ewes -low, medium and high - within each of the pasture groups.

One run, or solution, of the LP model was completed for each of the 36 scenarios. This required changes between runs in:

-- RHS values, to specify the availability of pasture land and of arable land with shallow or deep soil,

-- price or cost values, in the objective row, to bar selection of particular rotations and ewe regimes, and

-- matrix coefficients, in particular those for unimproved and improved pasture.

One simplifying assumption imposed on all 36 scenarios discourages the sale of cereal straw and vetch hay by reducing their sales prices to zero. This artificial condition has the effect of removing the off-farm competition for these feeds and thereby encourages on-farm sheep production. Removal of this restriction would be necessary in runs aimed at understanding the interactions of the farm with other farms and flocks.

Optimal Solutions:

Partial summaries of the solutions for all 36 scenarios are given in Tables 15 and 16: livestock and grain sales, and maximum whole-farm incomes are listed in the former; optimal numbers of ewes and annual quantities of main feed use are shown in the latter. Full details of solutions for all 36 scenarios are presented in Appendix A.

The values of sheep product sales, in Table 15, were derived in two steps. First, the quantities of milk, lamb and cull sales associated with one ewe (Table 6) were multiplied by the prices of these commodities (Table 8) and summed to find the revenue per ewe: SL 293, SL 373 and SL 460 for low, medium and high regime ewes, respectively. Then, these amounts were multiplied by the optimal number of ewes in the scenario solution (Appendix A).

The value of cereal grain sales was found by multiplying the quantity of grain sales in each scenario's optimal solution

TABLE 15. Optimal sales of sheep products and grain, and maximum farm profits under 36 resource and management scenarios.

Native Pasture Available:	None			10 ha Unimproved			10 ha Improved		
Ewe Regime:	Low	Med	High	Low	Med	High	Low	Med	High
BARLEY-FALLOW[1]									
Scenario:	1	2	3	4	5	6	7	8	9
Sheep Product Sales (000 SL)	--	--	--	7.8	7.3	5.3	14.1	12.5	11.9
Barley Grain Sales (000 SL)	8.1	8.1	8.1	7.6	7.0	6.7	7.1	7.2	4.9
Farm Profit (000 SL)	3.9	3.9	3.9	6.4	6.2	5.2	7.7	7.9	6.1
BARLEY-VETCH[2]									
Scenario:	10	11	12	13	14	15	16	17	18
Sheep Product Sales (000 SL)	14.7	16.3	13.6	19.3	21.4	17.7	25.8	27.8	21.8
Barley Grain Sales (000 SL)	14.0	13.8	14.0	13.8	13.7	14.0	13.0	13.4	14.0
Farm Profit (000 SL)	11.7	12.6	12.3	13.4	14.8	14.4	14.7	16.3	15.8
WHEAT-LENTIL-MELON[3]									
Scenario:	19	20	21	22	23	24	25	26	27
Sheep Product Sales (000 SL)	5.8	7.1	5.0	10.5	10.2	10.8	15.5	19.6	18.7
Wheat Grain Sales (000 SL)	7.2	6.7	6.8	7.6	7.7	7.7	7.2	7.7	7.7
Farm Profit (000 SL)	9.8	9.6	9.2	12.4	12.8	12.4	13.3	14.4	14.3
WHEAT-VETCH-MELON[4]									
Scenario:	28	29	30	31	32	33	34	35	36
Sheep Product Sales (000 SL)	11.9	14.2	11.8	15.9	19.4	15.8	20.6	24.4	20.1
Wheat Grain Sales (000 SL)	10.1	9.6	10.1	10.1	9.4	10.1	10.1	9.4	10.1
Farm Profit (000 SL)	15.3	16.2	16.1	16.9	18.3	18.2	17.9	19.6	19.6

Note, see:
1. Appendix Table A.1 for details on Barley-Fallow scenarios
2. Appendix Table A.2 for details on Barley-Vetch scenarios
3. Appendix Table A.3 for details on Wheat-Lentil-Melon scenarios
4. Appendix Table A.4 for details on Wheat-Vetch-Melon scenarios

TABLE 16. Optimal ewe numbers and feed use (in 100 kg units) under 36 resource and management scenarios.

Native Pasture Available:	None			10 ha Unimproved			10 ha Improved		
Ewe Regime:	Low	Med	High	Low	Med	High	Low	Med	High
BARLEY-FALLOW[1]									
Scenario:	1	2	3	4	5	6	7	8	9
No. of Ewes (head)	--	--	--	26.7	19.6	11.5	48.1	33.4	26.0
Barley Grain Fed	--	--	--	3.9	8.8	11.2	7.5	6.9	25.4
B. Stubbles Grzd	--	--	--	28.8	15.9	5.2	44.6	26.7	11.2
BARLEY-VETCH[2]									
Scenario:	10	11	12	13	14	15	16	17	18
No. of Ewes (head)	50.4	43.8	29.6	66.1	57.4	38.5	88.3	74.6	47.4
Barley Grain Fed	--	1.9	--	2.1	2.5	--	8.2	4.7	--
B. Stubbles Grzd	48.5	37.3	14.0	63.1	36.1	4.8	85.9	51.6	8.2
Vetch Past. Grzd	45.3	39.1	22.4	59.5	39.4	24.6	79.5	14.4	23.4
Vetch Hay Fed	47.8	51.5	61.6	39.3	51.4	60.3	27.3	66.4	61.0
Vetch Stub. Grzd	19.9	21.5	25.7	16.4	21.4	25.1	11.4	27.7	25.4
WHEAT-LENTIL-MELON[3]									
Scenario:	19	20	21	22	23	24	25	26	27
No. of Ewes (head)	20.0	19.1	10.9	36.0	27.4	23.5	52.9	52.6	40.6
Wheat Grain Fed	4.0	7.7	7.4	0.8	--	--	3.9	0.4	--
W. Stubbles Grzd	25.1	23.3	12.3	27.8	22.3	10.6	27.8	27.8	17.5
Lentil Seed Fed	2.9	6.7	5.4	0.9	1.0	11.0	--	13.8	20.3
Lentil Straw Fed	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1
WHEAT-VETCH-MELON[4]									
Scenario:	28	29	30	31	32	33	34	35	36
No. of Ewes (head)	40.8	38.2	25.6	54.4	51.9	34.4	70.4	65.4	43.6
Wheat Grain Fed	--	3.4	--	--	5.2	--	--	5.4	--
W. Stubbles Grzd	37.1	32.7	11.4	38.3	33.5	4.0	38.3	38.3	7.0
Vetch Past. Grzd	36.7	39.0	20.0	48.2	42.5	20.7	37.9	12.6	16.1
Vetch Hay Fed	45.6	44.2	55.7	38.7	42.1	55.2	44.9	60.1	58.0
Vetch Stub. Grzd	19.0	18.4	23.2	16.1	17.6	23.0	18.7	25.0	24.2

Note, see:

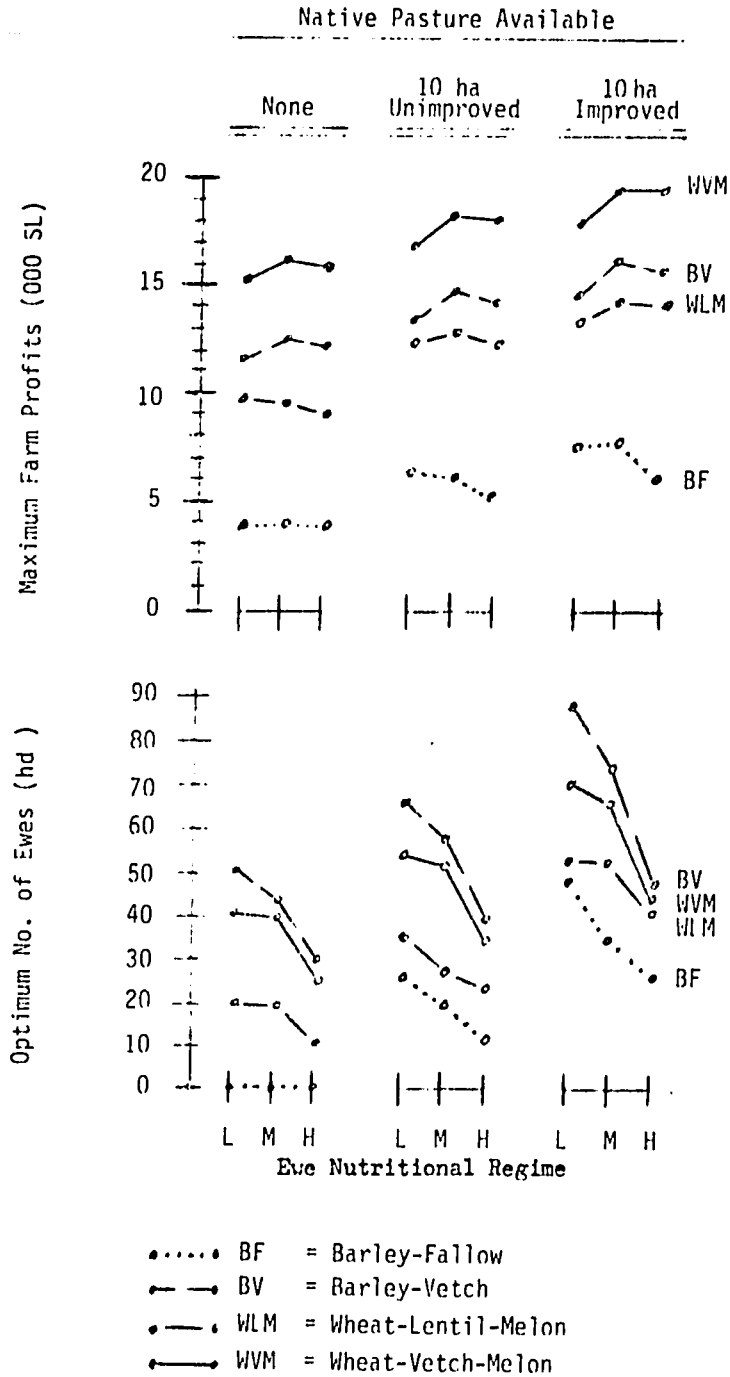
1. Appendix Table A.1 for details on Barley-Fallow scenarios
2. Appendix Table A.2 for details on Barley-Vetch scenarios
3. Appendix Table A.3 for details on Wheat-Lentil-Melon scenarios
4. Appendix Table A.4 for details on Wheat-Vetch-Melon scenarios

by the appropriate price (Table 8). The resulting grain sales values do tend to understate the whole value of the cereal crops, considering that the straw and stubbles are marketed only through the farmer's sheep, and that some of the grain is fed rather than sold (Table 16).

Substantial increases in the yields of cereal grains were associated with shifts from the traditional rotations to the high-input rotations with vetch. The relative revenues from sales of sheep products and cereal grains change between crop rotations and between native pasture resources. Where no native pasture is available, optimal ewe numbers are lowest and grain revenues may exceed sheep revenues. When native pasture is added to the farm's resource base, optimal ewe numbers increase and the sales value of their products exceed those of cereal grains. The only exception to this was in scenario No. 6, which calls for only a few sheep to complement the barley-fallow rotation.

The most significant results concerning maximum profits and optimal ewe numbers are presented in Figure 1. For a given ewe regime, the high-input rotations which include vetch, have higher maximum whole-farm profits and ewe numbers than the traditional rotations. In addition to their greater sheep carrying capacity, the high-input rotations owe part of their greater profits to the increased productivity of cereal crops.

FIGURE 1 Maximum Farm Profits and Optimal Ewe Numbers with 10 ha of Farm Land



Surprisingly, when native pasture is unavailable to complement the traditional barley-fallow rotation (scenarios 1 - 3), the optimal number of ewes is zero. In such cases, the costs of purchased supplements to meet the feed requirements of ewes on low, medium or high regimes could not be covered by the expected revenue from sheep products. Adding ewes to the farm operation under such conditions would reduce overall farm profits.

However, when vetch is grown in place of fallow, ewes enter the solutions and boost whole-farm profits substantially (scenarios 10 - 12). This is due to the on-farm availability of high quality vetch, used partly as pasture in spring, partly as hay in summer, fall and winter, and for stubble grazing in summer. In these scenarios, good use is also made of barley straw and stubble; this is in contrast to the non-use of these materials when the barley-fallow rotation is not complemented by native pasture (Table 16).

Within all rotations and ewe regimes, maximum whole-farm profits and optimal ewe numbers increase as unimproved (unfertilized) native pasture is added to the farm resource base. They increase further with a shift to improved (fertilized) native pasture. These increases in profits dramatically show the benefits of having access to "free" or inexpensively "improved" native pasture (Figure 1). However, the increases in optimal ewe numbers are proportionately greater than the increases in maximum whole-farm profits as native pasture resources are added.

Within all combinations of the four rotations and three native pasture scenarios, the optimal number of ewes decreases with a shift from the low to the high ewe regime. However, maximum whole-farm profits with the medium regimes were always greater than, or equal to, those with ewes on high regimes. Profitability relationships between low and medium regimes vary among the traditional crop rotations, while ewes on medium regimes are the most profitable with high-input rotations.

Given a particular ewe regime, sales of milk, lambs and cull ewes are proportional to the optimal number of ewes in each scenario. Since sales per ewe increase from the low to the high regimes, the decrease in total sheep product sales between the low and high regimes is smaller than the decrease in optimal ewe numbers. Because the decrease in optimal ewe numbers is largely offset by increased sales revenue per ewe as the nutritional regime improves, only minor differences in whole-farm profitability are found between regimes.

The increases in ewe productivity from low to high regimes are achieved by using more costly diets with higher nutrient densities. It is clear that ewes on low regimes make the fullest use of cereal stubbles (Table 16). For example, the 66.1 low ewes in scenario 13 would consume 6,310 kg of barley stubble, about 95 kg per head over the 120 day summer season, compared to only 12.5 kg per head for the high regime ewes in scenario 1 While only 480 kg of stubble is used in

scenario 15, profits are higher than in scenario 13 in which most of the available stubble is grazed.

For low regime ewes, the model tends to call for use of vetch pasture in spring rather than as hay later in the year (Table 16). This tendency is reversed for high regime ewes which require diets of higher nutrient density in fall and winter.

In most scenarios, the purchases of cottonseed cake and wheat bran are at, or near, the artificial 10% dry matter intake limits for the fall and winter seasons. This is due to the low prices and high nutrient densities of these feedstuffs.

In the process of determining optimal ewe numbers and maximum farm profits, the LP model simultaneously chooses minimum cost diets which satisfy the nutritional requirements of the ewes during each of the four seasons. Such diets are balanced using feedstuffs available from the crop rotation and from the market, in addition to native pasture herbage. The balance is also optimized across seasons and incorporates economic decisions on when and how best to use a vetch crop, native pasture and other feedstuffs.

Four examples of diet formulations, computed for medium regime ewes with each of the four crop rotations and 10 ha of unimproved native pasture (scenarios 5, 14, 23 and 32), are given in Table 17. The diets in each season are expressed in terms of the percentage of each ingredient in the dry matter intake in that season. In scenarios 14 and 32, cottonseed

TABLE 17. Optimal Diet Compositions (% of DM) for Medium Ewes on a 10 ha Farm with 10 ha of Unimproved Native Pasture

		Farm Soils:	SHALLOW		DEEP	
		Crop Rotation in Use:	BFROT	BVROT	WLMROT	WVMROT
		Scenario No:	**5**	**14**	**23**	**32**
ACTIVITY						
No	Code	**Summer Diet (%)**				
11	VSTUBS	vetch stubble	.	23.0	.	20.9
13	BSTUBS	barley stubble	50.3	38.8	.	.
14	WSTUBS	wheat stubble	.	.	50.2	39.8
51	NPSUMM	native pasture	43.4	29.4	21.2	39.2
52	NPSUSP	native pasture	6.3	8.8	28.6	.
			100.0%	100.0%	100.0%	99.9%
		Fall Diet (%)				
08	VHFALL	vetch hay	.	65.9	.	66.0
25	CSCPFA	cotton seed cake	10.0	17.0	9.9	17.0
27	WBPURF	wheat bran	10.0	17.0	9.9	17.0
30	BGFALL	barley grain	19.8	.	.	.
34	BSFALL	barley straw	52.5	.	.	.
42	WSFALL	wheat straw	.	.	33.9	.
45	LGFALL	lentil grain	.	.	2.3	.
48	LSFALL	lentil straw	.	.	44.0	.
53	NPFAWI	native pasture	7.6	.	.	.
			99.9%	99.9%	100.0%	100.0%
		Winter Diet (%)				
09	VHWINT	vetch hay	.	20.0	.	13.7
26	CSCPWI	cotton seed cake	9.9	9.9	9.2	9.9
28	WBPURW	wheat bran	9.9	9.9	10.0	10.0
31	BGWINT	barley grain	8.0	3.2	.	.
35	BSWINT	barley straw	23.6	57.0	.	.
39	WGWINT	wheat grain	.	.	.	7.4
43	WSWINT	wheat straw	.	.	16.8	46.1
49	LSWINT	lentil straw	.	.	64.0	.
53	NPFAWI	native pasture	9.1	.	.	.
55	NPWISP	native pasture	39.5	.	.	12.9
			100.0%	100.0%	100.0%	100.0%
		Spring Diet (%)				
06	VPSPRI	vetch pasture	.	62.1	.	75.9
36	BSSPRI	barley straw	35.1	5.8	.	.
44	WSSPRI	wheat straw	.	.	15.0	.
52	NPSUSP	native pasture	15.8	32.1	85.0	24.1
55	NPWISP	native pasture	49.1	.	.	.
			100.0%	100.0%	100.0%	100.0%

cake and wheat bran each comprise 17% of the calculated fall diets which are so high in nutrient density that daily intake is only 59% (10/17) of the maximum DM intake allowed.

The greatest differences in dietary formulations between scenarios are due to changes in the crop rotations. In both of the high-input rotations vetch, in various forms, appears in the diets of all four seasons. The timing of native pasture use also varies between the four crop rotations.

The diversity of the diets within and between seasons illustrates the flexibility of sheep to take advantage of a wide range of feedstuffs and grazing resources. This flexibility also means that many factors in the farming system must be considered simultaneously when determining the best bio-economic balance. That is why the LP technique is so useful: it is a convenient way to organize and use the available biological and economic information on a farming system when studying resource management problems.

Conclusions:

The conclusions drawn from the 36 scenario solutions may be summarized briefly. Combined with improved cereal agronomy and varieties, the addition of a vetch crop, in place of traditional fallow or lentils, allows intensified sheep production and higher whole-farm profits. Access to native pasture allows an increase in profits but requires higher capital investment in the form of greater numbers of

sheep. Only minor differences in farm profits are assocociated with the three ewe nutrition regimes. However, solutions with the high regime require fewer ewes than those with the low regime.

Neither the use of vetch pasture nor the production of vetch hay are common in NW Syria today. The present analysis suggests that such uses of this crop, with judicious managment, may be a key to more productive and profitable crop-livestock husbandry in similar environments.

CHAPTER 5. CAUTIONS AND FUTURE APPLICATIONS

The whole-farm model described in this document is a simplified view of a complex farming system. Therefore, some words of caution are necessary. Readers should be aware of the model's limitations so that due care is used in its interpretation and in its future applications.

The choice of "whole-farm profit maximization," as the objective criterion for optimization, can never truely represent the mix of family, social, religious, institutional and economic considerations which influence farmers' decisions. The model generates farm plans which are based on the profit motive alone, and constrained only by known limitations and relationships.

The nutrient requirements and production performance of ewes in the LP model are considered its most widely applicable feature. These sheep parameters should be valid for use in other parts of West Asia where the Awassi breed is found. This is because the two extreme nutritional regimes, low and high, are beyond the limits found in NW Syria. The 36 scenarios demonstrate that many possible mixes of feeds and grazing can be used to satisfy the nutrient requirements of these robust local sheep. The CP and ME values used for the various feeds are also widely applicable.

Mineral and vitamin requirements of the sheep have been ignored in the model and could be included in future

versions. Likewise, the feed and capital costs for carrying one ram for each 20 to 30 ewes, and for raising replacement animals, could be added. However, the errors caused by ignoring these aspects are thought to be minor in the present application.

No explicit constraints on labor, capital or equipment availability have been incorporated. Although these are constraints typically found in farm management LP models, they were not considered central to the questions of crop and feed balances. The model simply assumes labor is available at the going wage; equipment likewise may be hired, and there is no upper limit on capital use. A steady-state flock with annual replacement allowances avoids this question and ignores other opportunities for the capital invested in sheep.

The crop yield data used in the model are far less applicable to other areas than the sheep data. Applications of the rotation data to other areas, even those with similar environmental conditions, would have to be justified on a case-by-case basis and with considerable caution. These data can also be criticised for having come from scientist-managed rather than farmer-managed plots. Even so, the data are based on crops harvested from large plots managed with the intention of copying local practices as closely as possible, especially in the case of traditional rotations.

Substantial increases in the yields of cereals were

associated with the shift from traditional to high input rotations with vetch. These increases are due to the combined effects of improved cereal varieties and agronomic practices in addition to effects of vetch in these rotations. The design of the Unit Farm experiment did not allow quantitative separation of the effects of individual factors. This confounding, especially between the three year rotations, perhaps lead to a bias in favor of vetch when compared with lentils. The Unit Farm concept, of simulating farmers' practices on the research station, has been phased out in favor of replicated on-station and on-farm trials (Thomson, et al, 1983, Nordblom, et al, 1985, and Jaubert and Oglah, 1985).

Unlike the crop yield data discussed above, the structure of the crop section of the model should have wide applicability. All that is necessary is to insert yield and cost figures for the new location. The same can be said for the various feed purchase and crop sales activities.

Considerable caution is required in use of the model's native pasture component since this is based on preliminary results. But the herbage availabilities are good approximations. The data in this component of the model needs to be updated using reliable experimental results.

Future Applications:

The whole-farm LP model may be used in several ways: (1) to test other questions on bio-economic balances in farming systems of the Tel Hadya area, (2) as a framework for modeling other farming systems with similar mixes of activities, and (3) as a building block for expanded models which account for year-to-year variability in yields and prices.

Several examples of questions which may be approached through direct use of the model, are suggested below. These may be implemented through changes in objective row values, matrix coefficients or constraints in the present model and by examining shadow prices and boundary levels in the subsequent LP solutions.

1. How will increases in lentil productivity, due to improved practices and varieties, affect whole-farm profits? And how far far must lentil yields increase to make them competitive with forage crops?

2. How far must lentil harvest costs decrease before this crop becomes competitive with the vetch hay or pasture options? This question is important in the light of current ICARDA research on lentil harvest mechanization.

3. How far must the productivity of Awassi ewes on high nutritional regimes increase before they become consistently more profitable than ewes on medium regimes? This could

set target levels of performance for a genetic improvement project.

4. How will updating the native pasture coefficients affect farm profits?

5. How do the LP solutions change when sales of vetch hay, cereal straw and stubbles are allowed, or when the 10% limits on cottonseed cake and wheat bran are raised or removed? And, how sensitive are the solutions to price changes?

Expansion and adaptation of the present whole-farm model should make it possible to address more complex questions. Several examples are suggested here.

1. Year-to-year variation in crop yields, pasture availability and prices can be handled following appropriate modifications to the model (Murphy, 1971, Maerz, 1986). Such adaptations require more comprehensive data but appear justified by the importance of the issues involved.

2. Revision of the model to accommodate other farming systems is possible. For example, the comparison between a wheat-annual medicago rotation and traditional three course rotations.

3. The addition of lamb fattening activities to the model would only require a few adaptations to allow an alternative to the sale of weaned lambs at two months of age. Fattening lambs and breeding ewes would be competing users of the available feed resources.

4. Investment considerations, such as those in the establishment sequence of a wheat-annual medicago rotation, and how these affect decisions on sheep numbers and nutrition, deserve more research. Adaptations for such purposes might involve linking several "yearly modules" in a recursive chain, through which carryover feed stocks and sheep inventories from one year are considered as inputs to the next year. Each "yearly module" could be a matrix adapted from the present model, with crop yields varying from year to year.

The whole-farm model described in this document is a small step towards developing a more holistic view of the crop-livestock economies within which ICARDA's mandate crops are grown. Hopefully, this document will stimulate thinking and discussion among scientists in West Asia and North Africa. By developing such models, they will identify gaps in their knowledge concerning particular features of local farming systems. Thus, the model, and the suggested adaptations to it, should help in setting research priorities and assessing the impact of new farm technologies.

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APPENDIX A.1 Optimal LP solutions for 10 ha of arable land, with shallow soils, under a BARLEY-FALLOW rotation

		Native Pasture Available	NONE			10 ha UNIMPROVED			10 ha IMPROVED		
		Ewe Regime	Low	Med	High	Low	Med	High	Low	Med	High
		Scenario No.	1	2	3	4	5	6	7	8	9
ACTIVITY											
No	Code	Units									
01	BFBOT	0.1 ha	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
02	BVLOT	0.1 ha	.	.	.	.	.	.	.	.	.
03	WLHEOT	0.1 ha	.	.	.	.	.	.	.	.	.
04	WVMHOT	0.1 ha	.	.	.	.	.	.	.	.	.
05	VHOPT	100 kg	.	.	.	.	.	.	.	.	.
06	VPSPRI	100 kg	.	.	.	.	.	.	.	.	.
07	VHSUMM	100 kg	.	.	.	.	.	.	.	.	.
08	VHFALL	100 kg	.	.	.	.	.	.	.	.	.
09	VHWINT	100 kg	.	.	.	.	.	.	.	.	.
10	VHSPRI	100 kg	.	.	.	.	.	.	.	.	.
11	VSTUBS	100 kg	.	.	.	.	.	.	.	.	.
12	VHSALE	100 kg	.	.	.	.	.	.	.	.	.
13	BSTUBS	100 kg	.	.	.	28.8	15.9	5.2	44.6	26.7	11.2
14	WSTUBS	100 kg	.	.	.	.	.	.	.	.	.
15	BOSALE	100 kg	63.6	63.6	63.6	59.7	55.1	52.4	58.1	56.7	38.2
16	BSSALE	100 kg	34.0	34.0	34.0	.	.	27.1	.	.	18.4
17	WOSALE	100 kg	.	.	.	.	.	.	.	.	.
18	WSSALE	100 kg	.	.	.	.	.	.	.	.	.
19	LOSALE	100 kg	.	.	.	.	.	.	.	.	.
20	LSSALE	100 kg	.	.	.	.	.	.	.	.	.
21	WOSALE	mt	.	.	.	.	.	.	.	.	.
22	BOPUR	100 kg	.	.	.	.	.	.	.	.	.
23	BSPUR	100 kg	.	.	.	.	.	.	.	.	.
24	LSPUR	100 kg	.	.	.	.	.	.	.	.	.
25	CSCPFA	100 kg	.	.	.	3.8	3.2	2.1	6.9	5.4	4.7
26	CSCPWI	100 kg	.	.	.	1.6	2.6	1.7	1.8	4.5	3.9
27	WBPUEF	100 kg	.	.	.	3.8	3.2	2.1	6.9	5.4	4.7
28	WBPUEM	100 kg	.	.	.	3.2	2.6	1.7	5.8	4.5	3.9
29	BOSUMM	100 kg	.	.	.	.	.	.	.	.	.
30	BOFALL	100 kg	.	.	.	.	6.3	5.9	.	3.2	13.4
31	BOWINT	100 kg	.	.	.	3.9	2.1	5.3	7.5	3.7	12.0
32	BOSPRI	100 kg	.	.	.	.	.	.	.	.	.
33	BSSUMM	100 kg	.	.	.	.	.	.	.	.	.
34	BSFALL	100 kg	.	.	.	17.9	16.7	2.1	16.8	18.3	4.9
35	BSWINT	100 kg	.	.	.	16.1	6.2	.	17.2	10.6	.
36	BSSPRI	100 kg	.	.	.	.	11.1	4.8	.	5.1	10.8
37	WOSUMM	100 kg	.	.	.	.	.	.	.	.	.
38	WOFALL	100 kg	.	.	.	.	.	.	.	.	.
39	WOWINT	100 kg	.	.	.	.	.	.	.	.	.
40	WOSPRI	100 kg	.	.	.	.	.	.	.	.	.
41	WSSUMM	100 kg	.	.	.	.	.	.	.	.	.
42	WSFALL	100 kg	.	.	.	.	.	.	.	.	.
43	WSWINT	100 kg	.	.	.	.	.	.	.	.	.
44	WSSPRI	100 kg	.	.	.	.	.	.	.	.	.
45	LOFALL	100 kg	.	.	.	.	.	.	.	.	.
46	LOWINT	100 kg	.	.	.	.	.	.	.	.	.
47	LOSPRI	100 kg	.	.	.	.	.	.	.	.	.
48	LSFALL	100 kg	.	.	.	.	.	.	.	.	.
49	LSWINT	100 kg	.	.	.	.	.	.	.	.	.
50	LSSPRI	100 kg	.	.	.	.	.	.	.	.	.
51	NPSUMM	0.1 ha	.	.	.	.	22.9	15.2	.	4.6	13.6
52	NPSUSP	0.1 ha	.	.	.	64.0	13.4	42.4	49.3	51.9	48.1
53	NPFAWI	0.1 ha	.	.	.	30.6	11.9	42.3	36.6	43.5	38.4
54	NPWINT	0.1 ha	.	.	.	.	.	.	.	.	.
55	NPWISP	0.1 ha	.	.	.	5.3	51.8	.	14.1	.	.
56	NPSPRI	0.1 ha	.	.	.	.	.	.	.	.	.
57	LMEWE	head	.	.	.	26.7	.	.	48.1	.	.
58	MMEWE	head	.	.	.	.	19.6	.	.	33.4	.
59	MHEWE	head	.	.	.	.	.	11.5	.	.	26.0
60	MILKS	100 kg	.	.	.	10.7	9.8	6.9	19.2	16.7	15.6
61	LAMBS	100 kg	.	.	.	3.0	2.8	2.1	5.4	4.8	4.7
62	CULLS	100 kg	.	.	.	1.3	1.2	0.9	2.3	2.1	2.1
63	EWEPUR	head	.	.	.	26.7	19.6	11.5	48.1	33.4	26.0
MAX PROFIT		000 SL	3.9	3.9	3.9	6.4	6.2	5.3	7.7	7.9	6.1

APPENDIX A.2 Optimal LP solutions for 10 ha of arable land, with shallow soils, under a BARLEY-VETCH rotation

		Native Pasture Available:	NONE			10 ha UNIMPROVED			10 ha IMPROVED		
		Ewe Regime:	Low	Med	High	Low	Med	High	Low	Med	High
		Scenario No.	10	11	12	13	14	15	16	17	18
ACTIVITY											
No	Code	Units									
01	BFROT	0.1 ha									
02	BVROT	0.1 ha	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
03	WLWROT	0.1 ha									
04	WVWROT	0.1 ha									
05	VHOPT	100 kg	79.7	85.9	102.6	85.5	85.6	100.4	45.5	110.6	101.6
06	VPSPRI	100 kg	45.3	39.1	22.4	59.5	39.4	24.6	79.5	14.4	23.4
07	VHSUMM	100 kg	4.1	12.3	13.6					5.2	
08	VHFALL	100 kg	11.3	27.5	26.5	4.7	36.0	34.7		46.9	32.9
09	VHWINT	100 kg	32.4	11.7	21.5	34.6	15.4	25.6	27.3	14.3	28.1
10	VHSPRI	100 kg									
11	VSTUBS	100 kg	19.9	21.5	25.7	16.4	21.4	25.1	11.4	27.7	25.4
12	VHSALE	100 kg									
13	BSTUBS	100 kg	46.5	37.3	14.0	63.1	36.1	4.6	65.9	51.6	6.2
14	WSTUBS	100 kg									
15	BGSALE	100 kg	109.9	108.0	109.9	107.6	107.4	109.9	101.7	105.2	109.9
16	BSSALE	100 kg									
17	WGSALE	100 kg									
18	WSSALE	100 kg									
19	LGSALE	100 kg									
20	LSSALE	100 kg									
21	WMSALE	mt									
22	BGPUR	100 kg									
23	BSPUR	100 kg									
24	LSPUR	100 kg									
25	CSCPFA	100 kg	6.5	7.1	5.3	9.5	9.3	6.9	12.5	12.1	6.5
26	CSCPWI	100 kg		5.9	4.4		7.7	5.8		10.1	7.1
27	WBPURF	100 kg	7.3	7.1	5.3	9.5	9.3	6.9	12.7	12.1	6.5
28	WBPURW	100 kg	6.0	5.9	4.4	7.9	7.7	5.8	10.6	10.1	7.1
29	BGSUMM	100 kg									
30	BGFALL	100 kg									
31	BGWINT	100 kg		1.9		2.1	2.5		8.2	4.7	
32	BGSPRI	100 kg									
33	BSSUMM	100 kg									
34	BSFALL	100 kg	25.6		10.6	28.0		13.5	25.3		20.3
35	BSWINT	100 kg	22.0	33.7	11.3	19.6	44.1	10.9	22.5	47.8	13.7
36	BSSPRI	100 kg		14.1	25.7		3.7	23.5			13.8
37	WGSUMM	100 kg									
38	WGFALL	100 kg									
39	WGWINT	100 kg									
40	WGSPRI	100 kg									
41	WSSUMM	100 kg									
42	WSFALL	100 kg									
43	WSWINT	100 kg									
44	WSSPRI	100 kg									
45	LGFALL	100 kg									
46	LGWINT	100 kg									
47	LGSPRI	100 kg									
48	LSFALL	100 kg									
49	LSWINT	100 kg									
50	LSSPRI	100 kg									
51	NPSUMM	0.1 ha				26.0	45.5	65.7	25.4	8.0	32.2
52	NPSUSP	0.1 ha					54.5			64.4	37.7
53	NPFAMI	0.1 ha				74.0			74.6		30.1
54	NPWINT	0.1 ha									
55	NPWISP	0.1 ha						34.3		27.6	
56	NPSPRI	0.1 ha									
57	LMEWE	head	50.4			66.1			66.3		
58	WMEWE	head		43.6			57.4			74.6	
59	MEEWE	head			29.6			38.5			47.4
60	MILKS	100 kg	20.1	21.9	17.7	26.4	28.7	23.1	35.3	37.3	28.4
61	LAMBS	100 kg	5.6	6.3	5.3	7.4	8.3	6.9	9.9	10.7	8.5
62	CULLS	100 kg	2.4	2.8	2.4	3.2	3.6	3.1	4.2	4.7	3.8
63	EWEPUR	head	50.4	43.6	29.6	66.1	57.4	38.5	66.3	74.6	47.4
MAX PROFIT		000 $L	11.7	12.6	12.3	13.4	14.8	14.4	14.7	16.3	15.8

APPENDIX A.3 Optimal LP solutions for 10 ha of arable land, with deep soils, under a WHEAT-LENTIL-MELON rotation

Native Pasture Available:	NONE			10 ha UNIMPROVED			10 ha IMPROVED		
Eve Regime:	Low	Med	High	Low	Med	High	Low	Med	High
Scenario No.	19	20	21	22	23	24	25	26	27
ACTIVITY									
No Code Units									
01 BFROT 0.1 ha									
02 BVLOT 0.1 ha									
03 WLMROT 0.1 ha	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
04 WVMROT 0.1 ha									
05 VHOPT 100 kg									
06 VPSPRI 100 kg									
07 VHSUMM 100 kg									
08 VHFALL 100 kg									
09 VHWINT 100 kg									
10 VHSPRI 100 kg									
11 VSTUBS 100 kg									
12 VHSALE 100 kg									
13 BSTUBS 100 kg									
14 WSTUBS 100 kg	25.1	23.3	12.3	27.8	22.3	10.6	27.8	27.8	17.5
15 BGSALE 100 kg									
16 BSSALE 100 kg									
17 WGSALE 100 kg	53.1	49.4	49.8	56.3	57.1	57.1	53.2	56.8	57.1
18 WSSALE 100 kg			26.8						
19 LGSALE 100 kg	22.5	18.7	20.0	24.5	24.4	14.4	25.4	11.6	5.1
20 LSSALE 100 kg									
21 WMSALE mt	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
22 BGPUR 100 kg									
23 BSPUR 100 kg									
24 LSPUR 100 kg									
25 CSCPFA 100 kg	2.9	3.1	2.0	5.2	4.4	4.2	7.6	8.5	7.3
26 CSCPWI 100 kg		2.3	1.6		3.4	3.5		6.5	6.1
27 WBPURF 100 kg	2.9	3.1	2.0	5.2	4.4	4.2	7.6	8.5	7.3
28 WBPURM 100 kg	2.4	2.6	1.6	4.3	3.7	3.5	6.4	7.1	6.1
29 BGSUMM 100 kg									
30 BGFALL 100 kg									
31 BGWINT 100 kg									
32 BGSPRI 100 kg									
33 BSSUMM 100 kg									
34 BSFALL 100 kg									
35 BSWINT 100 kg									
36 BSSPRI 100 kg									
37 WGSUMM 100 kg	3.6	7.7	7.4						
38 WGFALL 100 kg									
39 WGWINT 100 kg	0.5			0.8			3.9	0.4	
40 WGSPRI 100 kg									
41 WSSUMM 100 kg									
42 WSFALL 100 kg	22.7	21.6		26.8	15.0	25.7	2.1		
43 WSWINT 100 kg		4.4			6.2	1.1	24.7	14.2	26.8
44 WSSPRI 100 kg	4.2	0.8			5.6			12.6	
45 LGFALL 100 kg	0.3	3.2	1.1	0.9	1.0	8.2		13.6	14.1
46 LGWINT 100 kg			1.0			2.3			6.3
47 LGSPRI 100 kg	2.5	3.5	3.3			0.5			
48 LSFALL 100 kg			14.6	5.1	19.5		4.0		7.7
49 LSWINT 100 kg	21.1	16.5	12.2	38.1	23.6	24.8	39.1	43.1	35.4
50 LSSPRI 100 kg	22.0	26.6	16.4			18.3			
51 WPSUMM 0.1 ha				7.8	15.6	37.3	3.8	12.8	18.8
52 WPSUSP 0.1 ha				92.2	84.4	62.7	87.8	84.8	81.2
53 WPFAMI 0.1 ha							28.4	2.8	
54 WPWINT 0.1 ha									
55 WPWISP 0.1 ha									
56 WPSPRI 0.1 ha									
57 LMEWE head	20.0			36.0			52.9		
58 MMSWE head		19.1			27.4			52.6	
59 MMEWE head			10.9			23.5			40.6
60 MILKS 100 kg	8.0	9.6	6.6	14.4	13.7	14.1	21.2	26.3	24.4
61 LAMBS 100 kg	2.2	2.8	2.0	4.0	3.9	4.2	5.9	7.6	7.3
62 CULLS 100 kg	9.6	1.2	0.9	1.7	1.7	1.9	2.5	3.3	3.2
63 EWEPOR head	20.0	19.1	10.9	36.0	27.4	23.5	52.9	52.6	40.6
MAX PROFIT 000 SL	9.8	9.6	9.2	12.4	12.8	12.4	13.3	14.4	14.3

APPENDIX A.4 Optimal LP solutions for 10 ha of arable land, with deep soils, under a WHEAT-VETCH-MELON rotation

Native Pasture Available:			NONE			10 ha UNIMPROVED			10 ha IMPROVED		
Eve Regime:			Low	Med	High	Low	Med	High	Low	Med	High
Scenario No.			28	29	30	31	32	33	34	35	36
ACTIVITY											
No	Code	Units									
01	BFROT	0.1 ha	.	.	.	.	.	.	.	.	.
02	BVROT	0.1 ha	.	.	.	.	.	.	.	.	.
03	WLKROT	0.1 ha	.	.	.	.	.	.	.	.	.
04	WVMROT	0.1 ha	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
05	VHOPT	100 kg	76.1	73.7	92.8	64.5	70.2	92.1	74.9	100.2	96.7
06	VPSPRI	100 kg	36.7	39.0	20.0	48.2	42.5	20.7	37.9	12.6	16.1
07	VHSUMM	100 kg	2.6	10.8	11.5	.	.	.	.	.	.
08	VHFALL	100 kg	14.7	24.0	25.5	3.7	32.6	33.0	1.2	41.1	31.4
09	VHWINT	100 kg	26.4	9.5	18.7	35.0	9.6	22.2	43.8	19.0	26.6
10	VHSPRI	100 kg	.	.	.	.	.	.	.	.	.
11	VSTUBS	100 kg	19.0	18.4	23.2	16.1	17.6	23.0	18.7	25.0	24.2
12	VHSALE	100 kg	.	.	.	.	.	.	.	.	.
13	BSTUBS	100 kg	.	.	.	.	.	.	.	.	.
14	WSTUBS	100 kg	37.1	32.7	11.4	38.3	33.5	4.0	38.3	38.3	7.0
15	BGSALE	100 kg	.	.	.	.	.	.	.	.	.
16	BSSALE	100 kg	.	.	.	.	.	.	.	.	.
17	WGSALE	100 kg	74.6	71.2	74.6	74.6	69.4	74.6	74.6	69.2	74.6
18	WSSALE	100 kg	.	.	.	.	.	.	.	.	.
19	LGSALE	100 kg	.	.	.	.	.	.	.	.	.
20	LSSALE	100 kg	.	.	.	.	.	.	.	.	.
21	WMSALE	mt	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
22	BGPUR	100 kg	.	.	.	.	.	.	.	.	.
23	BSPUR	100 kg	.	.	.	.	.	.	.	.	.
24	LSPUR	100 kg	.	.	.	.	.	.	.	.	.
25	CSCPFA	100 kg	4.0	6.2	4.6	7.8	8.4	6.2	10.1	10.6	7.9
26	CSCPWI	100 kg	.	5.2	3.8	.	6.9	5.2	.	8.8	6.5
27	WBPURF	100 kg	5.9	6.2	4.6	7.8	8.4	6.2	10.1	10.0	7.9
28	WBPURW	100 kg	4.9	5.2	3.8	6.5	7.0	5.2	8.5	8.8	6.5
29	BGSUMM	100 kg	.	.	.	.	.	.	.	.	.
30	BGFALL	100 kg	.	.	.	.	.	.	.	.	.
31	BGWINT	100 kg	.	.	.	.	.	.	.	.	.
32	BGSPRI	100 kg	.	.	.	.	.	.	.	.	.
33	BSSUMM	100 kg	.	.	.	.	.	.	.	.	.
34	BSFALL	100 kg	.	.	.	.	.	.	.	.	.
35	BSWINT	100 kg	.	.	.	.	.	.	.	.	.
36	BSSPRI	100 kg	.	.	.	.	.	.	.	.	.
37	WGSUMM	100 kg	.	.	.	.	.	.	.	.	.
38	WGFALL	100 kg	.	.	.	.	.	.	.	.	.
39	WGWINT	100 kg	.	3.4	.	.	5.2	.	.	5.4	.
40	WGSPRI	100 kg	.	.	.	.	.	.	.	.	.
41	WSSUMM	100 kg	.	.	.	.	.	.	2.6	.	.
42	WSFALL	100 kg	16.7	.	.	22.7	.	5.2	23.7	.	18.8
43	WSWINT	100 kg	15.7	28.3	10.0	9.6	32.3	8.7	6.0	32.3	12.9
44	WSSPRI	100 kg	.	4.0	22.3	.	.	18.4	.	.	0.0
45	LGFALL	100 kg	.	.	.	.	.	.	.	.	.
46	LGWINT	100 kg	.	.	.	.	.	.	.	.	.
47	LGSPRI	100 kg	.	.	.	.	.	.	.	.	.
48	LSFALL	100 kg	.	.	.	.	.	.	.	.	.
49	LSWINT	100 kg	.	.	.	.	.	.	.	.	.
50	LSSPRI	100 kg	.	.	.	.	.	.	.	.	.
51	NPSUMM	0.1 ha	.	.	.	29.5	55.0	58.2	13.4	18.4	23.0
52	NPSUSP	0.1 ha	.	.	.	.	.	.	34.0	49.8	51.2
53	NPFAWI	0.1 ha	.	.	.	68.1	.	.	52.5	.	25.7
54	NPWINT	0.1 ha	.	.	.	.	.	.	.	.	.
55	NPWISP	0.1 ha	.	.	.	2.4	45.0	41.8	.	31.8	.
56	NPSPRI	0.1 ha	.	.	.	.	.	.	.	.	.
57	LMEWE	head	40.8	.	.	54.4	.	.	70.4	.	.
58	MMEWE	head	.	38.2	.	.	51.9	.	.	65.4	.
59	MMEWE	head	.	.	25.6	.	.	34.4	.	.	43.6
60	MILKS	100 kg	18.3	19.1	15.3	21.8	25.9	20.6	28.2	32.7	26.2
61	LAMBS	100 kg	4.6	5.5	4.6	6.1	7.5	6.2	7.9	9.4	7.9
62	CULLS	100 kg	2.0	2.4	2.0	2.6	3.3	2.6	3.4	4.1	3.5
63	EWEPUR	head	40.8	38.2	25.6	54.4	51.9	34.4	70.4	65.4	43.6
MAX PROFIT		000 SL	15.3	16.2	16.1	16.9	18.3	18.2	17.9	19.8	19.6

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