Food from dry lands

An integrated approach to planning of agricultural development

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I. Spharim, R. Spharim & C.T. de Wit :

Modelling agricultural development strategy.Pag. 159-192

Kluwer Academic Publishers
DORDRECHT / BOSTON / LONDON

1992

7. Modelling agricultural development strategy

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7.1. **Introduction**

Development within an agricultural region can be defined as a change in infrastructure and technology that is undertaken to improve the productivity and welfare of the community. A 'technology' is a well defined production activity, whereby inputs are converted into products. There are many technologies available, but not all are feasible in the physical and socio-economic environment of a given region. The 'socio-economic environment' in the present context is expressed by the regional constraints and prices of inputs and products.

Analysis of options for regional agricultural development in a dynamic, integrated manner can be done with a suitable multiperiod, multiple-goal linear programming model (Hadley, 1982). Such a model selects mixes of technologies that will satisfy the development objectives subject to the regional constraints. The model simulates technological development in different regions and the effect of different socio-economic scenarios on technology selection and scheduling within a region. In this way, robust characteristics of a development path, that is, aspects that are not sensitive to change in scenario, can also be identified. Finally, the model is able to test the potential impact of technologies based on innovative techniques that are still being tested under experimental conditions. Selection of these technologies could then serve as a guide for selecting research proposals.

The multiperiod characteristic of the model simulates the time dimension of development and traces feasible development paths. This can provide regional planners with the capability for scheduling activities at the most appropriate time during the development process. The interactive multiple-goal mode provides a means whereby tradeoffs between different goals can be evaluated.

Any agricultural development model is by definition a simplification of a complex socio-economic, physical and biological system. Such a model aims to capture only those elements of the system that are relevant to the purpose of the study. Here the main purpose is to select those technologies that accord with the prevailing physical and socio-economic environment and best promote the development goals of the region and of other legitimate stakeholders. Such a model should have at least the ability:

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a. to select a set of products and production techniques that are best suited to the requirements of the region.
b. to represent the effect of external conditions (mainly reflected by the prices of products that are exported from the region and costs and availability of inputs that are imported into the region) on the selection of activities within the region.
c. to allow the necessary interaction between activities within the region.
d. to simulate the generation of financial capital as well as the investment, obsolescence and replacement of physical capital during the course of development.
e. to account for the effect of availability and reproduction potential of genetic stock on technology selection.
f. to identify technically feasible pathways for medium to long-term development processes.

All of these capabilities can be built into a linear programming model based on activities, constraints and goals. Activities represent production technologies that convert resources (inputs) into products or services (outputs). The resources include natural physical and biological resources that exist in the region and also inputs that are obtained from outside the region. Products or services can be used within a region or traded across the regional boundaries. The activities not only draw on limited resources (or constraints), but can also contribute to them. For instance, income generated in the region can be used to increase capital.

Activities can transfer quantities over time from one period to the next or in the same period from one production system to another. The first mode of transfer is characterized by activities such as capital formation. For example: financial capital in one year is transformed into physical capital in the next year, and this contributes capital services in the following years. A different type of capital formation is related to livestock population dynamics: female lambs born in one year are transformed into ewes that increase the livestock capital in the following year. The ewes produce products (lambs) or capital (female breeding lambs) and so forth. The other mode of transfer is of products produced by one activity as an input to another activity. For example, the grain producing activities, which can transfer the products grain and straw to the sheep husbandry activities where they are used as feed inputs.

Trade activities are channels that allow trade across the region borders. These include purchases of imported inputs, including fertilizers, concentrates or hired labour, as well as sales of products that are exported out of the region. Cash flow activities are those that relate to management and utilization of money for investment or consumption by the population in the region. The money for investment can be produced within the region, or borrowed from a lending agency or bank from outside the region or obtained as a grant from an international aid agency.

Constraints can also be divided into different categories. There are constraints which are natural resources that are not changed endogenously in the course of development. An example is total land area. This does not preclude the possibility of land reclamation that can change land productivity. Other constraints are resources that change as a result of development within the region. Examples are physical capital that can be increased by diverting part of the income generated to investment; or breeding stock that can increase by reproduction. A third category of constraints include those, like concentrate feed (fodder grains) or fertilizer, that can be produced within the region but can also be imported from outside. In the first and second constraint categories, the total available resources can be fully or partially exploited by the selected activities. In the third category of constraints, inputs are bought as needed and so the allocation among all participating activities is complete and the total for the region is balanced. For example, fertilizers are purchased according to the requirements of the selected activities, and there is no excess or deficiency of fertilizers, subject to the availability of money to purchase them. Another example is the constraint related to revenue that is allocated either to investment or to consumption and does not remain unused.

The goals, or targets, of development are defined either as outputs of activities that are to be maximized (like income) or constraints that can either be maximized or minimized. These include employment (maximize), fertilizer use (minimize), income for consumption by the people in the region (maximize), and so on. The treatment of multiple goals that may be imposed on a region will be discussed in greater detail later in this chapter (see Subchapters 7.3 and 7.4).

7.2. The multiperiod regional development model

The technique of linear programming (LP) requires that a set of relevant 'technologies', similar to those defined in Chapter 5, is translated into an equivalent set of 'activities'. Each activity is a set of coefficients (a vector) that relates all the relevant inputs of a specific production process to its outputs. The same conceptual pattern is used to define trade and capital formation activities which convert products to money via sale or purchase activities and revenue from sales to physical capital (buildings and equipment).

The activity vector describes the input/output relations per unit of a relevant production factor. Thus, cropping activities are normalized to the unit of land; livestock activities to the appropriate animal unit; investment, borrowing and consumption activities to the unit of money. The values of the target functions and the values of the solutions are also related to the unit to which each activity is normalized.

The linear programming method calculates the mix of activities that can use the available resources (constraints) most effectively to meet the goal. This goal or target function, can be the total revenue for consumption by the people in a region over a development period; or the number of settlers in a region subject to a minimum income constraint; or the need to reduce dependence on foreign aid; or the requirement to minimize the use of a particular polluting fertilizer.

An iterative procedure of multiple-goal optimization that does not assume that relative weights for each goal are known in advance will be considered in Subchapter 7.3.

The 'mix of activities' refers to the 'amounts' of each of the activities (or technologies) that are selected to maximize the target without violating any of the resource constraints. If such a mix can be formulated, then there is a 'feasible' solution. If not, then there is no feasible solution, unless some of the constraints can be made less severe. Expressed in concise mathematical forms, the LP problem is solved by maximizing (or minimizing) a target function, Z, subject to a set of constraints:

$$\text{Max } Z = x' * c$$

subject to $Ax \leq b$

$$x \geq 0$$

where,

x is the solution vector that contains the amount of each activity. The amount of an activity cannot be a negative number, and, therefore, each value in x is greater than or equal to zero.

c is a vector that defines the contribution of each activity to the selected target function.

A is the activity matrix, a matrix of technical coefficients with m constraints (rows) and n activities (columns), with r > m. The technical coefficients define the input or resource requirement per unit of product.

b is the vector of constraints, commonly called the right hand side (RHS). This defines the available resources and as a rule requires that they set an upper (or lower) limit to the utilization of that resource.

One of the main requirements of a development program is the scheduling of activities over a development path, while taking into account investment opportunities, obsolescence of physical capital and reinvestment policy. For this purpose the activity matrix of the linear program is elaborated into a multiperiod grand tableau. This grand tableau defines the interrelations between the production, trade and capital formation activities in the course of time. In the example of Figure 7–1, a development horizon of 15 years is considered. The diagonal elements A (1,1) – A (15,15) are the activity matrices for each year, whereas the non-diagonal elements A (2,1), A (3,1) – A (3,2) up to A (15,1) – A (15,14) handle the transfers of animals, physical and financial capital from one year to the next. Any physical assets, like fences, are assumed to be obsolete in a period of 7 years, so that there are at most 7 elements in a row or column of the grand tableau (Fig. 7–1). By means of this multiperiod configuration a mix of activities for each year is generated that optimizes the objective function for the whole time-horizon under consideration. In this way an optimum course of development is obtained in which some production activities fade out, others move in and still others stay the same or are not used at all. It thus identifies dynamically feasible and scheduled development paths.

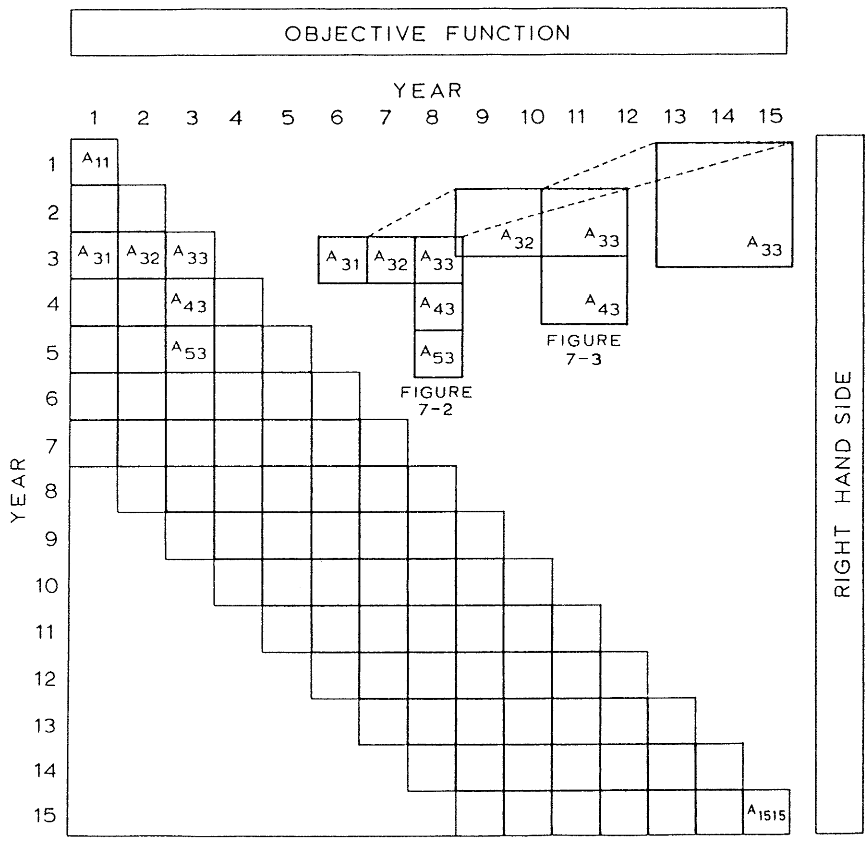

Fig. 7-1. Layout of the multi-period linear programming 'Grand Tableau'.

A closer view of the tableau for three consecutive years is given in Figure 7–2. The activities (columns) are divided into six main sections (I – VI) and are referred to by capital letters A-M in Figure 7–3; the constraints (rows) are divided into 13 categories and are referred to by the numbers 1–13. The activity matrix for one of the years and its links to adjacent years are presented in Figure 7–3. Activities are given here for the years (t-1) and (t), and constraints for the years (t) and (t + 1). The submatrix that is formed by the columns and rows for the year (t) is the activity matrix for that year, whereas the other two submatrices concern the transfer of animals and physical and financial capital from one year to the next. The detailed structure of the basic activity matrix, the 'A-matrix' is discussed in detail in Section 7.2.1.

In Figures 7–1 to 7–3, presentation of the actual coefficients for each activity is impractical in a schematic diagram because of the large number (more than a hundred) of production activities. The coefficients for these activities are calculated with the pasture system generator (PSG) described in Chapter 5 and

			year 1						year 2						year 3					
			Production	Capital formation &/or use	Intermediate products	Hired labour	Cross-border trade	Cash flows	Production	Capital formation &/or use	Intermediate products	Hired labour	Cross-border trade	Cash flows	Production	Capital formation &/or use	Intermediate products	Hired labour	Cross-border trade	Cash flows
			I	II	III	IV	V	VI	I	II	III	IV	V	VI	I	II	III	IV	V	VI
year 3	Natural resources	1																		
	Real capital	2		-1						-1						-1				
	Labour force	3																		
	Animal feed	4																		
	Fertilizer	5																		
	Other inputs	6																		
	Animals-ewes	7								-1					+1					
	Animals-breeders	8													-	+1				
	Mutton	9																		
	Main production: grain	10																		
	By-product: straw	11																		
	Money capital	12														+1				
	Revenue	13																		1.05
year 4	Natural resources	1																		
	Real capital	2														-1				
	Labour force	3																		
	Animal feed	4																		
	Fertilizer	5																		
	Other inputs	6																		
	Animals-ewes	7														-1				
	Animals-breeders	8																		
	Mutton	9																		
	Main production: grain	10																		
	By-product: straw	11																		
	Money capital	12																		-1
	Revenue	13																		
year 5	Natural resources	1																		
	Real capital	2														-1				
	Labour force	3																		
	Animal feed	4																		
	Fertilizer	5																		
	Other inputs	6																		
	Animals-ewes	7																		
	Animals-breeders	8																		
	Mutton	9																		
	Main production: grain	10																		
	By-product: straw	11																		
	Money capital	12																		
	Revenue	13																		

Fig. 7-2. Transfer matrices that enable the program to allocate resources from one year to the next and so facilitate optimization of the development process.

here it is only necessary to describe the relationship between the activities and the constraints. This is done with the following conventions: The symbol (+) in an element indicates that the activity concerned draws upon the constraint concerned and the symbol (−) that the activity contributes to the constraint. The constraints that act as units to which other inputs and outputs are related are indicated by either (+1) or (−1). In the present study there are animal units (ewes) in the pastoral activities, land units (ha) in the cropping activities and money units ($) in the trade and cash flow activities.

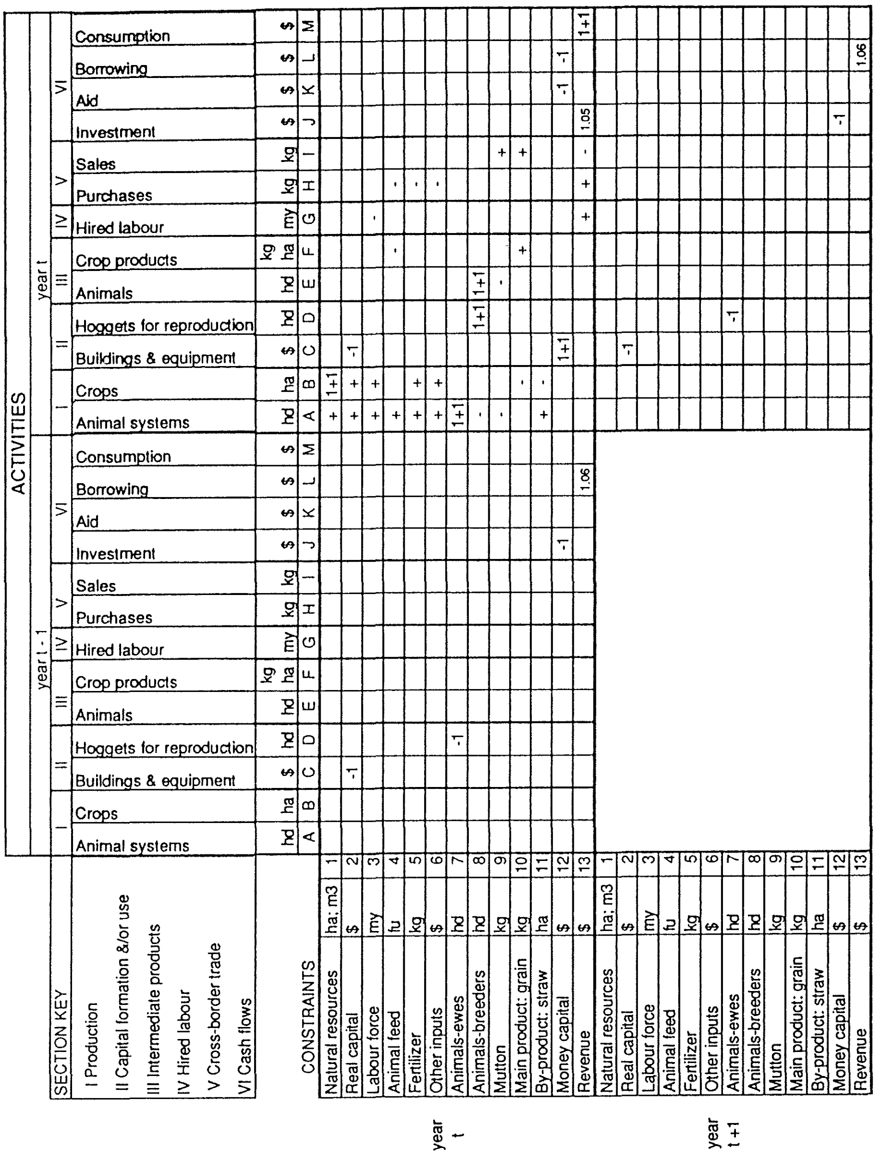

Fig. 7-3. The basic activity matrix, 'A', and its links to adjacent matrices.

7.2.1. *Activities and constraints*

The activities and constraints of Figure 7–3 are discussed here according to their main categories. The activity categories are the following:

Production activities. These are the actual and potential technologies that are relevant to the development of the region and include the animal production and cropping systems discussed in Chapter 5.

Capital formation activities. These represent the formation of physical and biological capital. Physical capital is formed by drawing on money capital and using it for structures, building and equipment acquisition. Biological capital is the genetic stock used for reproduction. It is formed by drawing on young female animals (potential breeders) in one year and converting them into reproductive breeding animals in the following year.

Intermediate products. These include:
- Animal products. This activity allows for the conversion of young potential breeders into meat products for sale.
- Crop products. This activity allows grain produced by the cropping activities to be sold or used as animal feed.

Hired labour (employment activity). This activity makes it possible to hire labour in addition to the permanent labour force in the agricultural sector of the region. In this way it contributes to the labour resource (or constraint) by drawing on revenue in the region. Because labour supply can be related to employment goals it is defined separately from the following group of activities.

Cross border trade. These are activities that allow import of services and products that serve as inputs to production activities and for export of products outside the region.

Cash flow activities. These include:
- Investment, which is the withdrawal of financial capital (money) from revenue in one year for investment in physical capital in the following year.
- External (foreign) aid that contributes to the available financial capital, *i.e.* the money available for investment. This is an external factor which allows for injection of funds to stimulate development. It does not have to be paid back to the contributor.
- Borrowing. This accounts for loans from financial sources not directly related to the production process in the region. It contributes to investment funds in one year, but must be returned with interest from available revenue in subsequent years.
- Consumption. This activity represents 'consumptive income', which is defined in the present study as income before taxes less investment. It draws on revenue and makes it available to the people in the region for consumption of products and services from outside the region or outside the agricultural sector.

The main constraints are:

Natural resources, like land (ha), that can be divided into categories relevant for the production activities of the region. Another limiting resource could be the amount of drinking water.

Real (physical and biological) capital, that includes fences, buildings and equipment already in the region at the beginning of the development horizon or acquired in the course of development. It also includes capital on the hoof, *i.e.* the ewes and the young breeding females (hoggets) that can be sold for meat or be retained and become breeding ewes in the following year.

Labour force, which refers to the permanently settled inhabitants of the region who conduct the production activities. They are considered as entrepreneurs who do not earn any wages but participate in the consumption of the revenue. As a constraint this labour force can be relaxed by hiring labour at the current wage rate from outside the region or the agricultural sector.

Tradable materials are concentrates, fertilizers and other miscellaneous inputs that are bought according to need, so that their stock is kept at zero.

Final intermediate products include lamb and mutton for sale as meat, main crop products, crop by-products and roughage.

Financial capital (money) is available for investment and can be adjusted by banking activities.

Revenue is divided between consumption, investments or saving. In years with very little revenue it is possible to borrow money to maintain the consumption level.

7.2.2. *Animal production activities*

The animal production activities are normalized on the ewe (Figure 7–3: '+1' in element A7 in year t). They draw (+) on natural resources (pasture land), physical capital (fences, structures, equipment), labour, fertilizer (for pasture fertilization) and can also draw on the locally produced grain or straw. They contribute (-) products for sale ('mutton') or young stock (hoggets) for breeding up the flock (Figure 7–3: '-' in elements A8 and A9 in year t). The crop production activities are normalized on a unit of land (Figure 7–3: '+1' in element B1 in year t). They draw on similar constraint categories as the livestock systems (except for 'ewes' and 'animal feed') and contribute to the crop products, wheat grain and straw (Figure 7–3: '-' in elements B10 and B11 in year t). The use of the wheat for sale or as animal feed is determined by the appropriate intermediate and trading activities F and I.

7.2.3. *Interactions with the socio-economic environment outside the region*

The boundaries of the region are determined by a logistic barrier that can be measured by the cost of transporting inputs into the region and products from the region to the market outside. These costs are influenced by institutional constraints (import quotas, duties), distance and the logistic efficiency of the transport system. They affect different products differently, some becoming untradable, others not. Tradable products not only include those that can be sold from the region, but also products that compete with local production. Among the items defined as 'non-tradable' in this model are the work of the permanent settlers, cultivable land and rangeland, and the breeding ewes. The tradable products are covered by the two trading activities: purchases (H) and sales (I) in year t. Purchases draw on revenue (' + ' in element H13 in year t) and contribute to animal feed, fertilizers and other inputs ('-' in elements H4, H5 and H6 in year t). Sales contribute to revenue ('-' in element I13 in year t) and draw on mutton (lambs or hoggets) and grain (' + ' in elements I9 and I10 in year t). Note that the intermediate animal products activity (E) draws on hoggets (' + 1' in element E8 in year t) and contributes to the 'mutton' that is for sale ('-' in element E9 in year t), the 'mutton yield' of each hogget depending on the specific livestock production technique. Male lambs are contributed by the animal production activities directly to the 'mutton' constraint, together with replacement ewes ('-' in element A9 in year t). Grain export is represented by the sales activity drawing on the grain constraint (' + ' in element I10 in year t) and contributing to revenue ('-' in element I13 in year t). The prices involved in these transactions are those current at the 'region gate'. Import of grains (for concentrate used as animal feed) is represented by the purchasing activity drawing on revenue (' + ' in element H13 in year t) and contributing to animal feed ('-' in element H4 in year t). Here, too, prices are those current at the 'region gate'. The difference between import and export prices of tradable products is an index of the 'height' of the logistic barrier.

7.2.4. *Interactions between activities within the region*

In agricultural production it often occurs that by-products are obtained in addition to the main product. Whereas the main product has a relatively high value per unit weight or volume, can cross the logistic barrier and thus be traded across the region boundaries, the by-products are bulky and of relatively low value. They can be used within the region as inputs for other production activities. These by-products can be important in the functioning of a region when they play the role of obligatory inputs for some activities. An example in this case would be straw that is used as supplementary roughage in certain sheep husbandry systems. In such cases the availability of straw can be a critical factor in determining the intensity of these activities. It is, therefore, important to take this interaction between activities into account. This is done as follows: The cropping activity contributes wheat grain and straw (' – ' in elements B10 and

B11 in year t). The straw is used by the animal husbandry activities that draw on the straw constraint ('+' in element A11 in year t); the crop product (intermediate) activity can draw on the grain yield ('+' in element F10 in year t) and contribute grain (as concentrate feed) to the animal feed constraint ('−' in element F4 in year t).

7.2.5. *Capital formation*

Agricultural development depends on enlargement of the means of production. This is done by increasing the physical and biological capital. The formation of physical capital includes the construction of structures and buildings and the acquirement of equipment (activity C). It draws on investment capital ('+1' in element C12 in year t) and converts (or contributes) it to physical capital ('−1' in element C2 in year t). Physical capital can be used without extra cost till it becomes obsolete. Thus in any year there are capital assets of various 'vintages' that appear as physical capital constraints. As long as physical capital is not obsolete, it can be used by various production activities, depending on how specific the capital item is. The wider its potential use by a large number of activities, the lower its specificity. This will be reflected by the symbol '+' appearing in a large number of activities that draw on a particular item of physical capital. In the model most sheep husbandry systems can use fences, which are non-specific, but only a few can use high technology artificial rearers.

In agricultural systems where the reproductive rate of the genetic stock (or biological capital) is low (like in livestock or dates), the availability of suitable breeds or cultivars can be a crucial constraint to rapid development. Where the logistic (or veterinary) barrier prevents trading in genetic stock, its availability must be taken into account. The specific feature of the genetic stock is that it can be sold to increase current revenues, or it can be kept to increase the available biological capital and so increase revenues in the following years. The model takes these two aspects into account in the following way: The animal husbandry systems contribute hoggets or young female lambs that can potentially be used for breeding when they become mature in the following year ('−' in element A8 in year t). The biological capital formation activity (D) draws on the store of breeding animals ('+1' in element D8 in year t) and contributes them to the reproductive flock in the following year ('−1' in element D7 in year t+1). However, the intermediate 'animal product' activity (E) can also draw on the available breeding animals (ewes and hoggets) ('+1' in element E8 in year t) and contribute them to the meat for sale (mutton) constraint ('−' in element E9 in year t). These animals are then not available for breeding in the following year. The sale activity (I) then draws on the mutton constraint ('+' in element E9 in year t) and contributes to revenue ('−' in element I13 in year t).

In this way the competition for hoggets between sale and breeding is maintained over the whole planning horizon, and ensures that whatever development path is selected, it will be feasible in terms of available genetic stock.

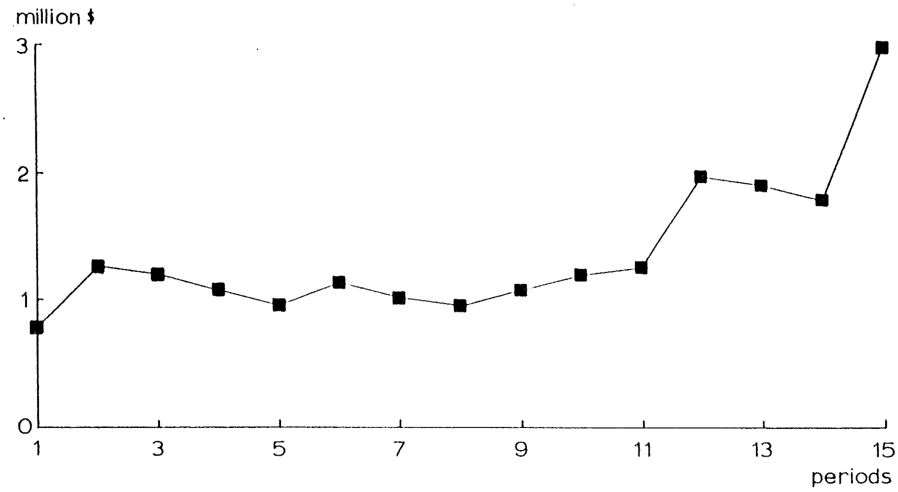

Fig. 7-4. Dynamics of regional consumption of revenue.

7.2.6. *Cash flow budget and time preference*

Capital formation requires investment which is financed from savings within the region or from external sources. The decision whether to invest, to consume or to save the available revenue will depend on many factors, one of the more important of which is the value of time which is determined by the attitude to consumption in the present in relation to investment, with the expectation of greater revenues for consumption in the future. The decision taken is also influenced by the cost of borrowing money and the benefit gained from saving for later investment in the production activities. The availability of money for investment in capital formation and the regional 'cash-flow' over the development horizon will, therefore, depend to a large degree on these factors.

The 'cash-flow' activities (VI, Figure 7–3) include investments necessary for new physical capital (structures, buildings and equipment, (J)), availability of external development aid (K), borrowing for investment through commercial loans (L) and consumption of revenue (M). The investment activity draws on revenue in any one year ('+1.05' in element J13 in year t) and contributes to investment capital in the following year ('−1' in element J12 in year t+1). It is assumed that the population in the region has a time preference for present consumption, so the investment activity bears a cost that draws more ('+1.05' in year t) than it contributes ('−1' in year t+1). The external (or foreign) development aid activity (K) contributes to investment capital ('−1' in element K12 in year t, the year in which the aid is given). This aid is in the nature of a grant and does not have to be paid back in subsequent years.

The borrowing activity (L) bears a cost of commercial funding from outside the region at the market interest rate, say 6 percent. This activity contributes to investment capital ('-1' in element L12 in year t) and draws on revenue in the following year ('$+1.06$' in element L13 in year $t+1$). The consumption activity draws on revenue ('$+1$' in element M13 in year t).

7.2.7. *Model output*

A regional scenario was defined and the model was run to gain an impression of the way it operates, and in particular, how some aspects of development change over the planning horizon. This scenario, the 'standard run', represents boundary conditions similar to those in the northern Negev of Israel and the selected target is 'maximum revenue for consumption'. It is, therefore, interesting to examine the course of revenue generation for consumption and investment as well as the regional dynamics of sheep breed composition.

The course of consumption is presented graphically in Figure 7–4. During the first years of development, regional consumption does not increase and even falls in some years as revenue is heavily used for investment instead of consumption. Investment drops to a more modest level as development proceeds. Consumption then rises dramatically towards the end of the planning horizon, whereas investments decline accordingly. If a project is to be liquidated at its termination, then this short term behaviour is a realistic result and opens up opportunities for investment in other projects. However, where regional development is expected to continue, the results that relate to the final years are a 'distortion' and should be ignored. This 'distortion' occurs because towards the end of the planning horizon, it becomes less desirable to make long-term investments and so more revenue is allocated to consumption, (or investment in other projects). In order to map out a longer development pathway, a longer planning horizon can be chosen, the practical period depending only on computer capacity. With a fifteen year planning horizon and continuing development, the model results are applicable for planning purposes only till about the eleventh year of the fifteen.

Selection of sheep breeds suitable for the regional development scenarios is based on the assumption that increase in genetic stock, in this case breeding ewes, can come about from local reproduction and to a limited extent only from imported animals or other more specialized technologies (artificial insemination or embryo transfer). The existing native landrace is the Awassi fat-tail used mainly for both lamb and milk production. As this standard run does not include sheep milk production as a tradable activity, the Awassi is at a disadvantage in comparison to the meat breeds, the German Mutton Merino (GMM) and the Finn cross (with Awassi and GMM). Consequently, the Awassi, which dominates in the first years of development gradually loses its dominance to the GMM and Finn cross, that are available in relatively small numbers at the beginning of development (Fig. 7–5). In the earlier years, the Awassi is fully exploited, while the GMM and the Finn cross are increased to the limit of their biological potential. In the eighth year, the number of GMM ewes exceeds the number of Awassi ewes for the first time, while the Finn cross

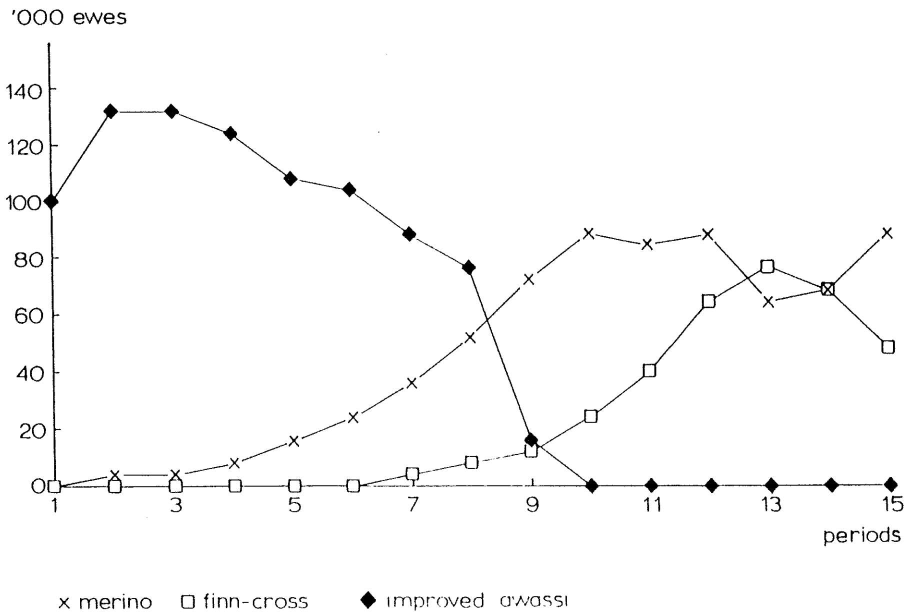

Fig. 7-5. Dynamic changes in breed mix over the development horizon.

becomes dominant later on. The flock composition in this run is the result of maximization of regional consumption. It is to be expected that consideration of other goals will change the sheep breed dynamics, but it is of interest to note that in the northern Negev the trend to higher fertility breeds has become evident in recent years.

7.2.8. *Testing model performance*

Can the model respond in a reasonable way to different socio-economic scenarios? In other words, do the results inspire enough confidence to justify their use as guide-lines for regional development and research planning? In order to check whether the model as defined in the A-matrix is operating as intended, some test runs were done to see if it could reproduce realistic technology mixes for widely different socio-economic situations and how it responds to smaller changes within such situations.

7.2.8.1. *Differentiation between regions*

Three different socio-economic regions were defined that roughly reflect the situation in the northern Negev of Israel, a region in the West Australian wheat belt and the coastal strip of the western desert of Egypt. All three areas are semi-arid with a mediterranean type climate. Dryland farming and extensive animal husbandry are the major agricultural practices. The population density is greatest in the Egyptian region and lowest in the Australian region; the distance

Table 7–1.
Definition of three typical regions.

Socio-economic characteristic	'Negev'	'W. Australia'	'W. Desert'
Prices – outputs ($ kg^{-1})			
Local market price, lamb	2.4	1.5	2.4
Export price of lamb	1.7	1.2	1.7
Export price of wheat	0.16	0.15	0.16
Prices – inputs			
Imported concentrates ($ kg^{-1})	0.15	0.17	0.15
Phosphorus fertilizer ($ kg P^{-1})	0.40	0.60	0.40
Nitrogen fertilizer ($ kg N^{-1})	0.30	0.60	0.30
Hired labour (10^3 $ person year^{-1})	10.0	10.0	5.0
Regional constraints			
Permanent settlers ($ person year^{-1})	400	100	1,000
Local market for lamb (kg mutton)	1×10^7	0.5×10^7	2×10^7

from markets is greatest in the Australian region and smallest in Israel. The local market for lamb is largest in the Egyptian region. In order to keep the test conditions relatively simple and open to fairly direct analysis, model performance was checked in relation to one goal only: maximization of revenue for consumption. The socio-economic environment is defined in terms of the prices of outputs and bought inputs, and in terms of regional constraints like the number of 'permanent settlers' and the local demand for lamb and mutton. This is a highly simplified definition of a region, but should be sufficient to illustrate the effect of regional characteristics on technology selection for development. A more detailed definition is given in Table 7–1. To simplify the comparison, the region is 50,000 ha in all three cases. The results of the runs are given in Table 7–2.

The model produces strikingly different results and technology mixes in the different socio-economic regions. Total regional income in the 'W. Australian' scenario is lowest, but income *per capita* is the highest. The cropping system there is overwhelmingly a wheat/legume rotation whereas in the 'Negev' and the 'W. Desert' it is mainly continuous grain cropping. In the 'W. Australian' scenario, the use of nitrogen fertilizer is lowest while the use of phosphorus fertilizer is highest; no imported concentrate feed is given at all, while in the other regions, it is used heavily. Whatever concentrate feed is given for fat-lamb production comes from the locally produced grain.

Despite the simplistic nature of this exercise and the fact that alternative feasible technologies like wool or sheep milk production were not included among the available technologies, the results of these runs reflect current development trends in the northern Negev of Israel and in the north-western coastal zone in Egypt. The trends suggested by the model for western Australia are much less realistic, because there the main relevant activities are based on

Table 7–2.
Summary of main results of 'typical region' development features (mid-development phase).

Item	'Negev'	'W. Australia'	'W. Desert'
Cumul. consumption (10^6 \$) [1]	244	64	282
Wheat area (10^3 ha yr^{-1}):			
- Continuous wheat	9.12	0	10.91
- Wheat/fallow rotation	0	1.15	0
- Wheat/legume rotation	7.82	17.07	4.82
Total wheat area	16.94	18.21	15.73
Straw area usage (10^3 ha yr^{-1}):	13.03	9.25	13.32
Concentrate imports (10^3 tons)			
- Obligatory concentrate	69.06	0	67.9
- Concentrate, replaceable by legume	2.64	0	6.3
Fertilizer use (10^3 tons):			
- Nitrogen	1.06	0.33	1.24
- Phosphorus	0.53	0.68	0.46
Grain utilization (10^3 tons):			
- Exported from region	20.71	10.05	20.70
- Used in the region	0 7.	84	0
Lamb and mutton marketing (10^3 tons)			
- Exported from region	4.33	5.79	0
- Used in the region	9.92	0.50	14.93

[1] Cumulative consumption over the 15-year development horizon.

fine wool Merino sheep in which wool is the main product and mutton is a by-product. These activities were not considered in the present version of the model. Including them requires data on the Australian sheep husbandry budget, that can then be translated into a vector of technical coefficients. That would enable planners to use the model to explore innovative technologies, including some that these days are being discussed intensively by scientists and pastoralists in Australia. The technologies concern the introduction of dedicated fat lamb production systems based on the Awassi breed that is particularly suitable for the live sheep export trade to the Middle East. This, as well as many other hypothetical alternative production systems could be assessed with the model before investing the huge amount of capital involved. In the same way, this model can be adapted to other situations, such as semi-arid regions in South America or the southern parts of the USA.

7.2.8.2. *Sensitivity to socio-economic scenarios*

The central purpose of the model is to select from a wide choice of technologies, a mix that will best serve the development goals in a specific socio-economic environment. The application of the model in a multiple-goal mode will be discussed in detail in the following subchapter. Here the impact of different regional socio-economic scenarios, specified by changes in the price ratios on the technology mix, will be examined.

Table 7–3a.
Parameter specifications for sensitivity runs (Prices in \$ kg^{-1}).

Run	1	2	3	4	5
Wheat for export	0.20	0.20	0.20	0.20	0.20
Imported concentrate	0.17	0.22	0.17	0.17	0.17
N-fertilizer	0.60	0.60	0.60	0.30	0.60
P-fertilizer	0.60	0.60	0.60	0.60	0.40
Lamb local market	2.20	2.20	1.70	2.20	2.20
Lamb export	1.70	1.70	1.70	1.70	1.70

Table 7–3b.
Summary of results of sensitivity runs.

Run number	1	2	3	4	5
Scenario [1]	Stand	Conc (+)	Lamb (-)	N-fert (-)	P-fert (-)
Cumulative consumption (10^6 \$)	205	184	144	209	207
CNO Concentrate use-obligatory (10^3 kg)	56.4	47.7	46.1	64.3	56.5
CNR Concentrate use-replaceable (10^3 kg)	0.06	0	0	15.8	0.2
FERN Fertilizer use-nitrogen (tons)	623	469	490	828	643
FERP Fertilizer use-phosphorus (tons)	669	717	727	664	674
Wheat exported from region (10^3 ton)	22.5	0.9	20.6	25.5	22.9
Wheat used as feed (10^3 ton)	9.45	8.68	8.66	9.63	9.46
Wheat area - continuous (10^3 ha)	5.98	0.37	3.25	10.82	6.57
Wheat area - wheat/fallow (10^3 ha)	0.77	0	0.28	0	0.61
Wheat area - wheat/legume (10^3 ha)	13.17	18.62	16.83	10.35	13.01
Total cultivated area (10^3 ha)	19.92	18.99	20.36	21.17	20.19
Straw area usage (10^3 ha)	13.55	9.68	12.02	16.00	13.87
Meat sold (10^3 \$)	12.4	8.5	11.4	13.4	32.3

[1] The deviations from the standard scenario are as follows:
Run 2 - higher concentrate price
Run 3 - lower lamb price
Run 4 - lower N-fertilizer price
Run 5 - lower P-fertilizer price
Details in Table 7-3a

As in the previous example the model was run to maximize revenue for consumption. The price changes are given in Table 7–3a and the solution to each of these changes in Table 7–3b. There are five scenarios. The baseline scenario is based on a physical and socio-economic environment appropriate for the northern Negev of Israel. Two scenarios (runs 2 and 3) represent more difficult economic conditions because of increased concentrate prices or decreased lamb prices while the ratio between the unit cost of concentrate and the unit price of lamb (1:10) is held constant. The last two scenarios represent better economic conditions for the producer because of cheaper N or P fertilizer.

The results (Table 7–3b) show that in the socio-economic environment of the northern Negev, lower lamb prices or higher concentrate feed prices tend to increase the desirability of the wheat/legume rotation, reduce the use of concentrate feed and of nitrogen fertilizer, and increase the use of phosphorus fertilizer. However, even though the lamb production profitability is lower, less wheat is produced because of the greater area under legume pasture. It is also of interest to note that even though the unit price ratio between imported concentrate feed and lamb was maintained constant, the resultant cumulative consumption and the selected technology mix were different. In particular, the area of wheat and consequently the quantity of wheat exported, was much lower when the price of imported concentrate was increased than when the price of lamb was reduced.

When the price of lamb and the price of imported concentrate both go down so that the same ratio is maintained, it does not mean that the profitability of production remains intact, because the price of locally produced inputs remains unchanged. This has two effects which in economic jargon are termed the 'expansion effect' and the 'substitution effect'. The lower profitability of lamb reduces lamb production and expands wheat production. The change in price ratio between imported inputs and locally produced inputs increases the substitution of imported concentrates by locally produced legumes.

Some other results are less surprising. Thus, for instance, the lower price for nitrogen fertilizer results in less of the cultivated land being used for the wheat/legume rotation and more for continuous wheat (Run 4). The reduction in the price of phosphorus fertilizer has virtually no effect on the solution (Run 5). This is a consequence of having defined activities with only one fixed level of phosphorus utilization, thus limiting the capacity of the model to respond. The effect of a price reduction in this case is, therefore, mainly to increase the income available for regional consumption.

The economic environment can change during a development project, generally within predictable bounds. Under such conditions of limited uncertainty, it is helpful to know how sensitive the desired development path is to such changes. The scenarios listed in Table 7–3a are distinguished from one another by changes in one factor at a time, and do not truly represent the more complex changes in scenario that involve a number of factors simultaneously. Nevertheless, they do indicate which characteristics are robust and which are sensitive to change. Among the robust characteristics is the development of breed composition:

- In all the runs, the Awassi gives way to the more prolific breeds, and would be maintained only if there were other non-economic reasons to do so.
- The area sown to wheat is not very sensitive to change.
- Only a very small area, if at all, is sown to the wheat/fallow rotation.

These examples show that under conditions of limited uncertainty, many elements of regional development are fairly robust and need not necessarily require major revision with moderate change in the economic environment.

7.3. **Interactive multiple-goal planning**

7.3.1. *Background*

In most situations where it is necessary to discriminate between different development possibilities there are several objectives and goals that must be satisfied, but since it is usually impossible to realize them all, they must be compromised, either explicitly or by default. According to Veeneklaas (1990), predictive planning strongly relies on insight into the underlying relationships between objectives and on an accurate assessment of existing restrictions, but in many planning situations these requirements cannot be met. Optimization and conventional planning require *a priori* weighting of objectives or permitted deviations from targets. When objectives or targets are expressed in different units of measurement and when, moreover, the objective function must be linear, the weighting procedures become too rigid and easily lead to artificial and consequently unsatisfactory constructions. Compromise planning does not assume that targets or relative weights for each objective are known in advance. The emphasis is on the generation of feasible and efficient technical solutions and active involvement of the policy maker in the decision process. The main task of the technician is to reduce the number of alternatives to a manageable level, while keeping a low profile in the process.

A so called 'satisfizing' (satisf[ying-optim]izing) method of reducing the number of alternatives is described by Simon (1955). A policy maker supplies minimum values he is willing to accept for each objective, and instead of seeking a best solution, he only seeks for a set of good solutions. Alternatives that do not satisfy his minimum requirements are not considered any further. Those that do, are again screened after increasing the minimum acceptable values of one or more of the objectives. When used in an iterative fashion, the number of alternatives can be reduced to very few and, if desired, to a single choice.

Such ideas were taken up by Hartog *et al.* (1979) in their study of the limits of the Welfare State and from there on further elaborated into an Interactive Multiple-Goal Programming (IMGP) procedure by Spronk and Veeneklaas (1983), van Driel *et al.*, (1982, 1983) and Veeneklaas (1990) to support the policy-oriented studies of the future, carried out by the Netherlands Scientific Council for Government Policy.

7.3.2. *A graphical illustration of Interactive Multiple-Goal Programming (IMGP)*

In the IMGP procedure the policy maker is presented with a number of iterations. Each iteration consists of a series of optimizations, the first iteration requiring at least as many as there are goal variables. These may typically be between five and ten. However, following van Driel *et al.* (1983), the procedure can be illustrated with a simple example using only two goal variables, consumption and employment, in the context of a region that fully depends on agro-pastoral activities. It is assumed that the policy maker wants to maximize both goals, even though they may conflict with each other. Therefore, in the first iteration consumption is maximized, but without setting any lower limit to employment and employment is maximized, but without setting any lower limit to consumption. The result is given in Figure 7–6a in the units 10^4 \$ and person-years. Since the values in this example do not have any significance on their own, they are further quoted without these dimensions. Point A presents the maximum consumption of 1,000. The employment happens then to be only 300.

Point B represents the maximum employment of 1,000 but then consumption happens to be only 100. If points A and B coincide, both goals are completely tied, so that realization of one brings with it the realization of the other. There is then no conflict of interest.

Point P1 (300,100) represents consumption when employment is maximized and employment when consumption is maximized. These two values are chosen as the lower bounds of the two goal variables, because it can be guaranteed to the policy maker that he does not have to accept lower values for these goals. The point I1(1,000, 1,000) in the figure combines the highest possible consumption with the highest employment and may be considered the ideal combination. It is, however, an utopian solution, since it is impossible to realize the maximum of two independently formulated, partially conflicting, goals at the same time. The rectangle P1AI1B contains, therefore, more than all possible alternatives for production. To illustrate this, the points A and I1 and B and I1 are joined by dotted lines.

All alternatives to the left of and below the lines P1A and P1B can be replaced by better ones. For instance, by moving from point P' to the right one arrives at an alternative which is always preferred because employment is higher at the same consumption. Therefore, by increasing the minimum goal restrictions to the point P1 no solutions that could be acceptable for the policy maker are excluded.

Given the ideal but utopian combination I1 and the most unfavourable combination P1, the policy maker is asked now which of the lower goal restrictions he wants to increase and to what extent. It should be pointed out to him that he does not commit himself because any value can be reconsidered. Let us assume that he first wants to ensure that consumption is at least 750. The most unfavourable combination of goal acl·ievement is then P2 (300, 750) as in

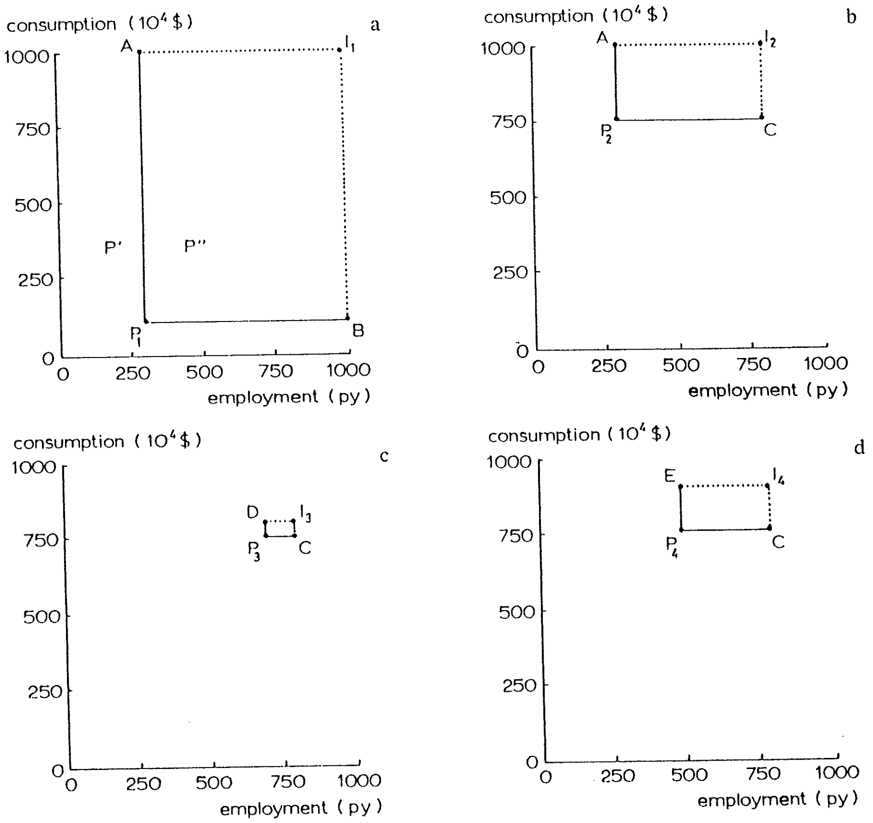

Fig. 7-6. a. specific production possibilities in case of no goal restrictions;
b. specific production possibilities under the goal restrictions that the consumption is at least 750 and the employment at least 300;
c. specific production possibilities under the goal restrictions that the consumption is at least 750 and the employment at least 700;
d. specific production possibilities under the goal restrictions that the consumption is at least 750 and the employment at least 500.

Figure 7–6b. This tightening of the goal restriction has its price and to determine this, it is necessary to execute a second iteration. The constraint that consumption has to be at least 750 does not change the possibility to reach the value of 1,000 at point A. Therefore, that optimization does not have to be repeated. However, it may appear now that the maximum employment that can be achieved is only 800 so that the original combination of goal values represented by point B in Figure 7–6a has to be replaced by point C (800, 750). The ideal or utopian alternative then moves to I2 (800, 1,000). This is the price that has to be paid for increasing the lower limit for consumption. If the policy maker considers this decrease in maximum employment acceptable, the tightened goal restriction for consumption is accepted, and he is asked again to tighten one of his lower limits.

Let it be assumed now that he increases the minimum acceptable employment to 700. Because this is lower than 800, this is a feasible demand. The most unfavourable combination of goal achievements now becomes P3 (700, 750) as in Figure 7–6c. It may then appear that the maximum consumption that can be realised is only 800, as given by point D in this figure. The ideal or utopian point moves then from I2 (800, 1,000) in Figure 7–6b down to I3 (800, 800) in Figure 7–6c. The feasible alternatives are now restricted to an employment between 700 and 800 and a consumption between 750 and 800.

It may be that the policy maker considers the reduction in possible consumption from 1,000 to 800 too large a sacrifice after all to guarantee that employment does not fall below 750. If so, he may reduce the lower limit for employment to for instance 500, *i.e.* halfway between the 300 that was considered too low and the 700 that resulted in an unacceptably low consumption. The points P4 (500, 750) and I4 (800, 900) in Figure 7–6d characterize his new margins.

The policy maker may continue until he arrives at a solution where the points P and I coincide and that he may consider satisfactory. However, he may also want a more detailed analysis of the future situation under those conditions. For that purpose he may request information on the animal husbandry techniques selected when consumption (point E in Figure 7–6d) or employment is maximized (point C). If he is not satisfied with this technology selection, he may want to start again at some preceding step, but with additional goal restrictions, such as the number of animals to be kept in feedlots. To improve his insight into the dependencies, he may also want to examine the shadow prices, that indicate how much the maximum of one goal decreases if the lower limit on another goal is increased by some small amount.

At this point, the investigator may want to re-examine the technical coefficients of the production techniques selected to verify that he has not been overly optimistic with respect to their performance, and if necessary to improve on them. In this way the interactive exercise that guides the policy maker in his regional planning also guides the investigator in his research planning.

The procedure is in principle the same if more than two goals are considered, but then the number of optimizations needed to arrive at a satisfactory solution increases rapidly with the number of goals. With three goals, already six iterations are necessary to tighten each of the goal restrictions once and per iteration the number of optimizations is equal to the number of goals. Since dynamic programs are in general time-consuming, available computing time may become a serious constraint when the activity matrix is large and the planning horizon is long.

It could be attempted to tighten two goal constraints at the same time, but then there may be no feasible solution for the optimization problem. In our example that would have been the case if, for instance, the minimum consumption would have been set at 810 and the minimum employment at 760 at the same time (see Figure 7–6c). The problem with such unfeasibilities is that they are expensive, because it takes the solution algorithm often considerable effort to find this out.

Another possibility to reduce the number of iterations considerably is not to reset a goal after its optimization but to retain a more satisfactory value. In that way the feasibility of subsequent optimizations in the iteration round is ensured, but the danger exists that the policy maker is guided so rapidly to a solution corner, that all options which may be of interest are not explored. Experience shows that this danger is limited if two full iteration rounds have been completed, but by then the most time consuming and expensive optimizations have been performed.

7.4. **An example of the application**

7.4.1. *The initial conditions*

The method was applied to the northern Negev region of Israel, a mediterranean region, with winter rainfall as explained in Section 7.2.8. To define the region for the present purpose, both cultivable land with a high production potential, usable for both arable farming and rangeland and uncultivable hilly rangeland, were assumed to occupy 25,000 ha each. The initial number of settlers in the region was, rather arbitrarily, set at 400. The genetic stock at the beginning of the development period comprised 100,000 Awassi ewes, 2,000 Merino ewes and 200 Finn cross ewes. The minimum price for hired labour was set at $ 5,000 per person-year. In the 'standard' run, prices for tradable products per kg were set at $ 0.20 for wheat exported out of the region, $ 0.17 for imported concentrates, $ 0.60 for N and P fertilizer, $ 1.7 for mutton on the export market and $ 2.2 for mutton on the local market.

7.4.2. *The goals*

The potentials of the interactive multiple-goal linear programming technique are best exploited, when the number of goals specified in the model is initially set at a high number. That provides optimum flexibility and allows one to keep the technically feasible development pathways as open as possible (van Eijk *et al.*, 1986). In the example presented here, the following goals have been defined:

- Development aid, *i.e.* money for imported capital goods that is made available to the region at no cost and does not have to be repaid in the course of development. When this goal is set to zero, the possibilities for the region to develop on its own can be investigated. On the other hand, allowing infusion of limited amounts of development aid could indicate the scope for stimulating effects of such investments.
- Use of imported concentrates. Minimization of this goal could serve the national government, especially if the costs of imported concentrates include

a substantial proportion of foreign exchange. However, that may increase the need for import of fertilizers for production of feed locally, because nutrient availability is a major constraint for production (Chapter 3).

- Consumption by the local population, defined as income before taxes less investment. Maximizing consumption over time is a goal of the local settlers. Consumption may also be a goal of the national government in as far as it serves as a tax base.
- Employment. Maximum employment opportunities are a common development goal. In this respect a distinction is made between the local settlers for whom no alternative employment opportunities are assumed, and migrant, hired labour that has to be paid. Restricting the number of settlers and allowing unrestricted hiring and firing of migrant labour would be in the interest of the local population, but increasing the population without creating unemployment may be the goal of the national government or a settlement agency.
- Traditional system conservation. This goal of maintaining traditional production techniques and animal breeds in the region may be motivated by arguments relating to maintenance of environmental diversity and preserving animal and plant genetic stock. For the purpose of illustration, such extensive production techniques can be based on the local Awassi sheep breed, grazing yearlong without fencing, and with roughage as the main supplementary feed.

7.4.3. *The policy views*

To illustrate the capabilities of the multiple-goal linear programming technique for the purpose of agricultural development planning, three policy alternatives were formulated:

- The view of the present settlers, based on free enterprise. Their goals can be summarised as: restricting the number of settlers, maximize consumptive income for the present population, unlimited hiring and firing of migrant labour, no more than a minimum area with traditional production techniques, and no limitations on the use of imported concentrates.
- The view of a settlement agency, whose goals include: maximization of the number of settlers, with an income at least equal to that of the price of hired labour, low unemployment, no specific requirements with respect to the area under traditional production techniques and no limitations on the import of concentrate feed.
- The view of a conservationist group. Their goals include minimum use of imported concentrates, a large area under traditional production techniques, a reasonable number of settlers in the region, with an equitable income, and limited use of migrant labour.

Table 7–4.
Upper and lower limits over a fifteen-year period for three goal variables as determined in the second iteration cycle of MGLP.

Goal maximized	Values of goal variables		
	Cons. income 10^6 \$	Employment 10^2 pers.-year	Traditional systems 10^3 ha
Cons. income	197 a)	135	112
Employment	50 c)	192 a)	100 b)
Traditional systems	50 c)	58 b)	742 a)

a) upper limit; b) lower limit; c) lower bound.

7.4.4. *Results*

The extreme attainable values of the goal variables were determined one by one, while setting the requirements on the other goals either at their lowest physical limit or at a very modest level. This procedure provides for each of the goal variables the highest value that can possibly be attained and sets also the lowest value that need be accepted. After this first iteration cycle it was decided that the region had sufficient potential to develop without external financial resources, hence development aid was not further investigated, and set to zero. Additionally, consumptive income, necessary for the local population over the planning horizon, was estimated to be at least \$ 50 million, derived from the average number of settlers over the period and the price of hired labour. In the subsequent iteration cycle, three goals, reflecting the different policy views were further examined: consumptive income, employment and the area under traditional production techniques. The results of those optimization runs are given in Table 7–4. When consumptive income was maximized, a value of \$ 197 million could be achieved, which under the prevailing economic conditions thus represents the maximum. In the runs where the two other goals were maximized, consumptive income drops to \$ 50 million only, hence the lower bound set in the model. When employment is maximized, a total of 19,200 person-years can be achieved over the total planning horizon of 15 years, whereas employment only reaches 5,800 person-years in the situation where the area under traditional production techniques is maximized. When the area under traditional production techniques is maximized, a total of 742,000 ha-years can be exploited in that way over the planning horizon of 15 years, out of a physical maximum of 750,000 ha-years. The requirement of a minimum consumptive income of 50 million dollars prevents complete utilization of the land under traditional production techniques. In the run where employment is maximized, only 100,000 ha-years under traditional production techniques are chosen, which defines the lower value that needs to be accepted.

The results in Table 7–4 define the solution space for the region in the absence of outside financial aid. For the further analysis it was assumed that the

Table 7–5.
Upper and lower limits over a fifteen-year-period for two goal variables as determined in the third iteration cycle of MGLP, serving the policy of the conservationist group.

Goal maximized	Values of goal variables		
	Cons. income 10^6 \$	Employment 10^2 pers.-year	Traditional systems 10^3 ha
Cons. income	144 a)	113 b)	600 c)
Employment	90 b)	131 a)	600 c)

a) upper limit; b) lower limit; c) lower bound.

conservationist interest group considered both the consumptive income of \$ 50 million and the employment of 5,800 person-years too low, but was prepared to accept a decrease in the area under traditional production techniques to 80 percent of the potential. That requirement was, therefore, introduced in the model as the lower bound and consumptive income and employment were optimized again. The results of this iteration round (Table 7–5) show that under these conditions consumptive income ranges between \$ 90 and 144 million, and employment between 11,300 and 13,100 person-years. The conservationist group, reflecting on these results decided that employment should at least be 12,500 person-years. Setting that value as the lower bound in the model, and optimizing again for consumptive income resulted in a value of \$ 135 million. Hence, the conservationist's 'world' provides the region with a consumptive income of \$ 135 million and a total employment of 12,500 person-years, which implies an annual income before taxes of about double that of hired labour. These results could of course be challenged by one of the other interest groups, who could argue that such a high proportion of traditional production techniques in the land use of the region involves too high a cost in terms of consumptive income, or employment. A further analysis can then be carried out, in which the consequences of these views can be analysed quantitatively, so that gain in consumptive income and/or employment can be expressed in terms of the sacrifices required in reduced area under traditional production techniques.

The consequences of various policy options for selection of production techniques and the output of the region are now elaborated. The policy options examined are basically identical to those defined before, but some additional bounds on the goal variables were defined: for the settlement agency and the settlers a lower bound of 75,000 ha under traditional production techniques was introduced, for the conservationist interest group import of concentrate feed was not allowed, and for the settlement agency hire of migrant labour was restricted to 200 person-years per year.

The results are presented in Table 7–6, showing that total employment varies between 10,600 and 15,000 person-years over the 15-year period. The settler's policy favours restriction of the total number of settlers, and as a consequence,

Table 7–6.
Summary of results of the MGLP model for three policy views, under the limiting goal variable values imposed.

Interest group	Conservationist interest group	Settlement agency	Settlers
Employment	13,000	15,000	10,000 p.yr
Settlers	11,740	14,800	6,000 p.yr
Linear growth rate settlers	43	74	0 $p.yr.yr^{-1}$
Hired labour	1,260	200	4,600 p.yr
Consumptive income	121	196	169 10^6 $
Consumptive income per settler	11	14	28 10^3 $\$.yr^{-1}$
Average results for years 7-12 (expressed on a per year basis)			
Mutton sale local market	5.5	9.7	9.1 10^6 kg
Mutton sale export	0	1.5	0.7 10^6 kg
Wheat sale export	0	11.3	15.2 10^6 kg
Imported concentrates	0	33.6	30.1 10^6 kg
Intermediate use wheat	13.4	7.7	0.2 10^6 kg
Roughage (straw) production	8.9	11.2	8.0 10^6 kg
N fertilizer use	1.6	0.65	0.6 10^6 kg
P fertilizer use	0.24	0.87	0.6 10^6 kg
Area wheat/fallow	0	0	0 ha
Area wheat/wheat	8,400	3,700	100 ha
Area wheat/legume	851	15,100	16,900 ha
Total area wheat	9,251	18,800	17,000 ha
Area extensive production techniques	60	12	8.3 10^3 ha
Total concentrate use (imported, wheat grain, legume straw)	104	359	327 kg ewe^{-1}
Investments	1.9	2.1	4.3 10^6 $

it also requires the most hired labour. Total consumptive income is intermediate in this policy view, but as the number of settlers is low, the *per capita* income per settler is by far the highest in this scenario.

The scenario set by the settlement agency leads to the highest total employment, and, not surprisingly, to the highest growth rate of settlers in the region. Total consumptive income is also highest here, but because of the high rate of increase of settlers in the region, *per capita* income is only half of that achieved under the scenario favoured by the local population. However, before taxes it is still three times higher than the cost of hired labour.

Implementation of the development plan of the conservationist group leads to an intermediate level of employment, with a lower increase in population growth in the region. Both, total consumptive income and income *per capita* are

Table 7–7.
Sheep husbandry systems selected by the model expressed in ewe equivalents under the three scenario's, averages of year 7–12 (see also Tables 5–1 and 5–2).

Code	Environmentalist group	Settlement agency	Settlers
Group V, rangeland, unfenced, roughage			
impr-yearl-norm,G=0.7	4,600	0	0
impr-yearl-norm,G=0.9	22,700	13,000	8,200
GMM -defer-earl,G=1.6	0	17,300	320
total group V	27,300	30,300	8,520
Group VI, rangeland, fenced, concentrates			
impr-yearl-norm,G=0.9	0	700	4,100
GMM -defer-norm,G=1.4	0	0	5,700
GMM -defer-earl,G=1.6	0	0	13,200
total group VI	0	700	23,000
Group I, cultivable land, unfenced, roughage			
impr-yearl-norm,G=0.9	84,800	0	0
impr-green-norm,G=1.0	10,000	0	0
GMM -green-norm,G=1.7	15,100	0	0
GMM -green-norm,G=2.0	8	0	0
total group I	109,908	0	0
Group II, cultivable land, unfenced, concentrates			
impr-yearl-norm,G=0.9	0	16,400	3,300
impr-green-norm,G=1.0	0	3,200	0
GMM -defer-earl,G=1.6	0	2,400	0
GMM -green-earl,G=1.9	0	21,200	0
total group II	0	43,200	3,300
Group IV, cultivable land, fenced, concentrates			
impr -yearl-norm,G=0.9	0	2,000	19,700
impr -green-norm,G=1.0	0	7,400	0
GMM -defer-norm,G=1.4	0	0	11,300
GMM -defer-earl,G=1.6	0	3,100	3,900
GMM -green-norm,G=1.7	0	0	400
GMM -green-earl,G=1.9	0	0	21,700
FinnX-green-earl,G=2.4	0	0	3,300
total group IV	0	12,500	63,900
Group VII, feedlot, roughage			
GMM -norm,G=1.7	83	0	0
FinnX-norm,G=2.0	2	0	0
total group VII	85	0	0
Group VIII, feedlot, concentrates			
GMM -earl,G=1.9	0	27,950	10,400
FinnX-earl,G=2.4	0	27,150	23,800
total group VIII		55,100	34,200
Total number of sheep of various breeds			
Awassi	0	0	0
Improved Awassi	122,100	42,700	35,300
German Mutton Merino	15,191	71,950	66,520
Finn Cross	2	27,150	27,100
total number of sheep	137,293	141,800	128,920

the lowest under this scenario, but the latter is still twice as high as that assumed for hired labour.

Technology selection has been analysed for the period from 7–12 years after the start of the development period. This period has been chosen to avoid distortions due to initialization and 'termination' artefacts, as explained in the preceding section.

Annual mutton production in the region is highest in the scenario advocated by the settlement agency, *i.e.* 11.2 million kg. The mutton produced for export is valued at a lower price than that for the local market. In the settlement agency's scenario only about 13 percent of the total production has to be exported. The lowest mutton production results when the policy scenario of the conservationist group is implemented, as can be expected under the condition of import restrictions on concentrate feed. That constraint is, however, partially alleviated by increased use of locally produced wheat grain as a substitute, a practice that is less favoured in the other two scenario's, as the price of imported concentrate is lower than that of exported grain. The consequence of the increased grain production for animal feed is, that in the conservationist's scenario the use of nitrogen fertilizer is relatively high. However, this is considered acceptable because the efficiency of nitrogen in semi-arid regions is high (Chapter 3). Since there are hardly any feedlots in this scenario (Table 7–8), there is no farmyard manure available to reduce the use of industrial fertilizer. More farmyard manure is produced in the other scenarios, but proper storage and use of farmyard manure for wheat fertilization is too expensive. It is treated here as waste, *i.e.* as long as government regulations allow it.

With regard to arable farming, continuous wheat cultivation is favoured in the scenario of the conservationist, while the wheat/legume rotation is heavily favoured in the two other scenario's. The wheat/fallow rotation is never selected. It indeed is a relatively uncommon practice in the region, but it is sometimes practiced for phytosanitary reasons. The wheat/legume rotation is favoured in the scenario's of the settlers and the settlement agency, as it reduces the dependence on expensive imported concentrate, and hence increases consumptive income. That is an explicit goal of the settlers, and an implicit goal of the settlement agency, as a minimum livelihood for increased numbers of settlers is aimed at.

Definition of system parameters:

Sheep breed: impr = Awassi under improved management;
GMM = German Mutton Merino; FinnX = Finncross.
Grazing system: yearl = yearlong; green = green season only
(includes early dry season when quality of pasture is still high);
defer = yearlong except for deferment during transitional period after opening winter rains.
Weaning system: norm = normal weaning; earl = early weaning
G = net lambing rate: lambs weaned per ewe per year.

The lowest investments are necessary in the scenario for the conservationist group, mainly because the requirement for a large area under traditional production techniques reduces the need for expensive fencing. In addition, the total wheat area is smaller, so that investments for capital assets associated with wheat cultivation are not necessary. The highest investments are required in the scenario favoured by the settlers. These needs are associated with extensive use of labour-saving fences, building of physical structures and equipment on both rangeland and cultivable land.

The various sheep husbandry systems selected by the model in the three scenario's are summarized in Table 7–7, again as averages for the period 7–12 years. In the scenario favoured by the conservationist group, Awassi under improved management is by far the most selected sheep breed. All sheep husbandry techniques selected are on unfenced land, and feedlot operations are hardly selected. In the scenario's of the settlers and the settlement agency, sheep breed selection is very similar, with slightly over half the animals being Merinos, the remainder being equally split between Awassi under improved management and Finn-cross ewes.

The main difference between the development scenario of the settlers and that of the settlement agency is that in the former most of the sheep production techniques are practiced on fenced land, while in the latter production techniques on unfenced land prevail. Evidently, that is a consequence of the employment requirements imposed on the model, as herding on unfenced land requires substantially more labour. Also feedlot operations are selected to a larger extent by the settlement agency, as these are relatively labour-intensive too.

7.5. **Discussion**

The interactive multiple-goal linear programming technique can help planners who have to analyse agricultural development possibilities on a regional basis. It is a tool they can use to choose between different feasible development pathways under a wide range of technical and socio-economic conditions. The model can incorporate a large amount of general and local knowledge on actual and potential production techniques, regional physical and socio-economic resources and constraints and prices of inputs and outputs. This makes it possible to conduct an analysis of a dynamic planning process that explicitly takes into account a large number of technical possibilities and regional interests. The model has a strong technical base, in which socio-economic constraints, like ownership of the means of production, distribution of income, and uncertain economic behaviour are not considered. This approach avoids the very complex problems associated with these aspects of development and allows for full, untrammelled analysis of a wide range of technically feasible development pathways including innovative, unexpected ones. As a consequence of this approach, the results may raise too optimistic expectations for development in a region. For instance, a desirable development may require common use of scarce resources, which may only be possible through policy measures aiming at promoting or even forcing cooperation, and legislation may be required to regulate such cooperation. Here the political dimension comes into play and the analysis can help to define the benefits and costs that could motivate desirable change. The socio-economic dimension is then also clearly presented with its 'margins for policy' (de Wit *et al.*, 1988). It is, therefore, not only a convenience, but important in principle, to separate as strictly as possible the technical coefficients of the present and possible alternative agricultural production techniques on the one hand and the socio-economic environment in which they are to be implemented on the other. The consequences of a proposed development pathway can be evaluated in terms of economic viability and social acceptability. If some of the socio-economic constraints then appear insurmountable over the planning horizon, it may be necessary to change some of the goal restrictions or to introduce new constraints and repeat the planning exercise until a workable plan is attained.

By quantifying the implications of implementing a certain viewpoint, such a model can also serve as a basis for negotiations between various interest groups in a region. That may lead to a compromise and so provide a broader base for the proposed regional development plan. In this way the results of the model can be used to improve communication between planners and policy makers and between policy makers and various interest groups in a region. This can help to smooth the way to a more balanced development in which the interests of all the parties that are involved are taken into account.

The validity of the model results depends on many factors. These include the accuracy of the technical coefficients in the input-output model, the proper definition and quantification of the goal variables and the degree to which the technical and socio-economic possibilities can be treated separately. Technical coefficients for present production techniques often can be determined with sufficient accuracy on the basis of the general body of knowledge in a region. However, there is a danger that the technical coefficients of alternative production techniques are estimated too optimistically by their advocates and critical evaluation is, therefore, necessary. Equally important are the goal variables, which are often difficult to identify, difficult to translate into terms relevant for the model and difficult to quantify.

The separation of technical and socio-economic aspects, which is an essential feature of the approach, makes it possible to distinguish between the technical possibilities in a region and the elusive behavioural factors that often strongly influence actual development policies. As a result, the analysis can help to define political issues more meaningfully, and so '... grant unto Caesar what is Caesar's', while pointing to feasible pathways for development. In this way, the discussions about development options can be conducted in more tangible terms, and so make communication between different stakeholders easier and more to the point.

The results of such an analysis are only an intermediate step in formulating actual development policies. The model results indicate the requirements for promotion of desired development options, but they do not answer the question as to what policy measures are necessary to actually bring them about. A post-model analysis is necessary to translate the requirements for external inputs, investments, education, research, etc. into practical actions. In this analysis the social acceptability of the proposed developments should be given special, careful consideration.

7.6. Conclusions

The interactive multiple-goal linear programming technique for analysis of rural development possibilities can perform a number of important functions:
- Identification of consistent, technically feasible development pathways for a region, that promote a combination of goal values considered most acceptable to the stakeholders in the sector.
- Evaluation of the cost of achieving full realization of one goal in terms of the sacrifices that are imposed by regional constraints on other goals.
- Translation of the selected combination of goal values into a set of production techniques that are required for their achievement.

These can be expressed as requirements for land reclamation, imports of means of production, export of products, credit facilities, education, etc. This analysis can provide a choice of technically feasible options that can serve as a well-constructed objective basis for further socio-economic and policy analysis.

Appendix

Model activities and constraints by categories

Activities

I.	Production	
	A. Animal production systems (108 technologies)	head
	B. Crops	
	Grain – grain	
	Grain – fallow	
	Grain – legume	
II.	Capital formation and/or use	
	C. Buildings and equipment	$
	Animal buildings and machinery on range land	
	Fences on range land	
	Animal buildings and machinery on cultivable land	
	Fences on cultivable land	
	Artificial lamb rearing units	
	Equipment for crop cultivation	
	D. Retention of hoggets for reproduction	head
	Awassi	

	Improved Awassi	
	German Meat Merino	
	Finn Cross	
III.	Intermediate products	
	E. Animals	head
	Awassi lambs	
	Improved Awassi lambs	
	German Meat Merino lambs	
	Finn Cross lambs	
	F. Crop products	kg
	Grain for obligatory concentrate feed	
	Grain or legume pasture for replaceable concentrate feed	
	Straw	
IV.	Hired labour	
	G. Hired labour	person-year
V.	Trade across the regional border	
	H. Purchases	
	Obligatory concentrate feed	kg
	Replaceable concentrate feed	kg
	Nitrogen fertilizer	kg
	Phosphorus fertilizer	kg
	Other purchased inputs	$
	I. Sales	
	Mutton for the domestic market	
	Mutton for the export market	
	Grain	
VI.	Cash flows	$
	J. Investment	
	K. Aid	
	L. Borrowing	
	M. Consumption	

Constraints

1.	Natural resources	
	Range area	ha
	Cultivable area	ha
	Water for livestock	m^3
2.	Capital stock	$
	Animal buildings and machinery on range land	
	Fences on range land	
	Animal buildings and machinery on cultivable land	
	Fences on cultivable land	
	Artificial lamb rearing units	
	Equipment for crop cultivation	
3.	Labour force	person-year
4.	Animal feed	FU
	Obligatory concentrate feed	

	Replaceable concentrate feed	
	Roughage	
5.	Fertilizer	kg
	Nitrogen fertilizer	
	Phosphorus fertilizer	
6.	Other inputs	$
7.	Animals-ewes	head
	Awassi	
	German Meat Merino	
	Finn Cross	
8.	Animals-hoggets	head
	Awassi	
	Improved Awassi	
	German Meat Merino	
	Finn Cross	
9.	Mutton	kg
	Lamb and culls for export	
	Lamb and culls for the domestic market	
10.	Main crop products	kg
	Grain	
11.	Secondary crop products	ha
	Straw	
12.	Investment capital	$
13.	Revenue	$