8. Summary

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8.1. Introduction

Is water the dominant constraint to primary production in semi-arid regions? That question sparked the study described in this book. At an early stage it became clear that nutrient deficiency was at least as important, and even more so in average to good rainfall years. Consequently, the study was expanded to include the effects of improved nutrient availability on pasture growth and crop yields in the semi-arid environment of the northern Negev. This led to the development and analysis of crop and sheep husbandry systems that were designed to utilize the arable land and improved pastures more efficiently. The choice of agro-pastoral systems whereby primary and secondary production can be integrated in a given region was the next subject to be broached and led to the problem of considering simultaneously relevant agro-ecological as well as socio-economic constraints that apply to regional agricultural development.

As conditions change and especially when active development is pursued, far reaching and rapid changes in husbandry systems become the order of the day as old-established traditional systems and even newer systems become obsolete. Innovative adaptations have to be identified, usually under conditions of increasing uncertainty with regard to the future. To analyse the possibilities for regional development, a three-step approach was elaborated. First, the feasibility and robustness of selected innovative techniques at the farm level were investigated in relation to variabilities in weather and prices, then a matrix of production techniques for a region was formulated in terms of their physical inputs and outputs, and finally this matrix was embedded into a dynamic multiple-goal linear programming model that facilitated the exploration of different development pathways in dependence of socio-economic aspirations and constraints.

8.2. Primary production

Vegetation that grows in the rainy winter of a semi-arid mediterranean climate must be able to survive the long, hot and dry summer. Apart from deep-rooting dwarf shrubs, annuals that enter the dry period in the form of seeds are well

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adapted to this situation. Most of these have an extended and flexible period of seed formation, so that even in years when the first rains are late or when late rains fail, enough seeds are usually formed for the species to survive. These species, and in particular those that do not have characteristics that are objectionable to foraging ruminants (like thistles, sharp awns or noxious constituents), provide a good basis for animal production.

The quality of these annuals as animal feed is characterized mainly by their protein content and digestibility. These depend to a large extent on the growing conditions. While phosphorus may be deficient in some soils in the semi-arid mediterranean regions, nitrogen is always in short supply. This becomes obvious in wet years when nitrogen fertilizer must be supplied in considerable amounts to achieve a situation in which water is the constraining factor. If then no fertilizer is added, the limited amount of nitrogen available is diluted to such an extent that the protein content in the material approaches its minimum value. In dry years, when water is the limiting factor and biomass production is low, the vegetation has a high protein content even at maturity, because the amount of nitrogen available from natural sources is diluted much less. These observations were confirmed by experimental results that also served to verify dynamic simulation models of annual pasture growth under conditions of limited water availability. These analyses also showed that the potential production rate of native pastures, particularly during the vegetative period, was identical to that of pastures of cultivated species or small grain crops. The differences in final yield were the result of different phenological patterns and growing periods as well as differences in allocation of assimilates between the various plant organs.

Comparison of the calculated and actual production levels over a thirteen-year period showed that in most of the years the available amount of water could have indeed supported a considerably higher production. Hence, the water resource, although scarce, is very much under-utilized in semi-arid regions. Fertilizer application can thus increase the average yield of native pastures considerably but, as yields in drought years are not affected, it also increases the year-to-year variability.

Since seasonal rainfall cannot be predicted, expensive fertilizer applied in years that turn out to be dry can be a financial burden. Fortunately, under semi-arid conditions, and particularly in a dry year, losses of nitrogen by leaching or denitrification are small. Consequently, most of the applied nitrogen that is not recovered from the soil by the vegetation in the year of application because of lack of water, is available for vegetation growth in the following year. With an appropriate fertilizer application strategy, fertilizer use efficiency can be maintained at a high level so that, eventually, most of the fertilizer nitrogen applied to pasture ends up as crude protein that can be utilized by grazing livestock. Phosphorus is in general not lacking in mediterranean pastures, and where it is, its application poses no specific problems beyond those of an economic nature.

In small grains, nitrogen deficiency limits growth and dry matter production in the same way but the effect on grain yield involves a major complication: a liberal supply of nitrogen may stimulate early growth to such an extent, that the water in the soil is exhausted before seed filling starts. When this happens, grain yield is lower as a consequence of nitrogen application.

Both natural and fertilized native pastures produce far more seed than is required for regeneration of the pasture in the following year. Most of these seeds are 'harvested' by granivores, mainly ants but also rodents and birds. As a rule, the remaining seed stock, usually protected in refuges provided by the soil and residual vegetation, is sufficient to ensure establishment of the vegetation in the subsequent year. The combination of fertilizer application and green season grazing radically changed the species composition of the pasture. While this change did not endanger continuity of exploitation, it did reduce species diversity and the species that came to dominate the pasture were not necessarily the most valuable. Nevertheless, both primary and secondary production were dramatically increased and viable measures are available to improve the vegetation of pastures that became dominated by less desirable pasture species.

Utilization of the vigorous pasture growth achieved by fertilizer application requires high stocking densities. The average growth rate of fertilized pasture during its grand period of growth is about 100 kg dry matter per ha per day, except in drought years. Since the maximum intake per ewe is normally less than 3 kg per day, very high stocking densities would be needed for defoliation to affect production seriously. However, in the early growing season during the first two months after germination, growth rates are much lower because of incomplete soil cover and low temperatures. At that stage, heavy grazing of the highly nutritious young vegetation can significantly reduce seasonal production and the tradeoff between immediate benefit and total pasture production must be considered, particularly when other feed sources may be scarce. Consequently, the subject of grazing deferment at the beginning of the growing season was analysed in detail.

The same considerations apply to very early grazing of wheat. Here not only total dry matter production but also grain yield is important. It could be shown that this was hardly affected, even by heavy grazing, during a period of up to three weeks between canopy closure and the start of stem elongation. When pasture is scarce, particularly during the early part of the season, this extra bite can be important and is another good reason for integrating arable and pastoral land use.

8.3. Secondary production

Sheep are better adapted to a semi-arid annual vegetation type than cattle. Their shorter reproductive cycle facilitates adaptation to the strong seasonality of primary production and their early puberty makes it easier to adjust flock size to annual climatic or economic fluctuations. If pasture production is low, feed requirements for lactation can be reduced by early weaning of lambs and if pasture production is high, out of season lambing is possible. Adjustments to different production levels can also be realized by appropriate choiçe of sheep breeds and management systems. In areas where productivity of natural pasture is low, hardy, well adapted native breeds with moderate prolificacy, like the Awassi, predominate. Traditional systems, based on this breed, are characterized by single-lamb litters and by a lambing frequency of once per year in good years and lower frequencies during periods of extended nutritional stress. Intensification of production beyond a modest improvement, either by the use of supplementary feed or by pasture improvement, soon requires the use of breeds with higher prolificacy. In Israel, at first the emphasis was on improved management of the Awassi breed, but at a later stage German Mutton Merino sheep were imported. The introduction of rams of the prolific Finnish land race and Romanov breeds resulted in crosses that produced twins and triplets, so pushing the average prolificacy up to 1.65 lambs per ewe per lambing. With multiple breeding of up to 3 lambings every two years, the lamb crop can be increased to more than 2 lambs per ewe. However, because of the greater dependence on supplementary feeds and susceptibility of the crosses to diseases, more care is required and as a result, their full production potential can be attained only in intensively managed feedlot systems.

In improved grazing environments the emphasis shifts from per animal production to per unit area production and this is closely related to stocking rate. The experimental work centered, therefore, around the interactions between stocking rate and herbage production, the fraction consumed in the growing season and the daily herbage intake of individual sheep. In general, there is a diminishing return in the production per sheep as stocking rate increases. However, sheep production per unit area continues to increase with increasing stocking rates well beyond the point where per sheep production begins to decrease. In intensive agro-pastoral systems sheep are not only supplemented because of the low quality of the dry pasture during part of the year, but also when sheep performance declines due to overstocking. However, the added cost may significantly reduce the economic efficiency of the system. In addition, annual variation in pasture production, particularly when fertilizer is added to the pasture, is a complicating factor. If under these conditions flock size is fixed at a level that prevents overexploitation in dry years, large amounts of good quality grass are wasted in favourable years. Fertilization is then hardly attractive. On the other hand, if the grass is fertilized and flock size is adjusted to a level that leads to utilization of most of the grass in more favourable years, feed shortages occur in drier years. These can be overcome only to a limited degree by increased culling and sale of unproductive animals and so it may be necessary to resort to more supplementary feeding. Fertilization of natural pastures in semi-arid regions is, therefore, invariably accompanied by stocking rates adapted to the more favourable years, and supplementary feeding, even during the growing season, in the drier years. The level of intensification justified by the prevailing bio-physical, climatic and socio-economic conditions must be carefully considered, and the analysis can involve a complex array of factors. Some of the models developed as part of this study were designed to facilitate such an analysis.

8.4. The matrix of production techniques

A matrix of production techniques was used to construct a multiple-goal programming model that contains the technical coefficients that specify the inputs and outputs of all the appropriate agro-pastoral systems that are known to be relevant to semi-arid regions with winter rains. The production techniques are essentially the same in different regions, but quantitative differences exist, due to differences in soil and climate. The technical coefficients of the more extensive pastoral systems and of feedlot operations can be derived from a common base of knowledge and experience. However, systems characterized by a more intensive land use, are less well understood and their technical coefficients can only be derived from a sometimes speculative combination of the existing base of knowledge with new information on primary and secondary production, as presented in this book.

To cover the whole spectrum of options, a systematic approach has been developed, in which the systems are distinguished on the basis of breed, land unit, fencing, fertilizer regime, grazing regime and the use of arable crops and legumes. The systems also differ in their use of labour, transport, buildings, watering points, veterinary services and the level of technological know-how that is required. Apart from some mutton and wool, the main output of each technology is lamb meat. All inputs and outputs are long-term averages defined in physical terms with the ewe as a common denominator.

The procedure for deriving the technical coefficients is target oriented in the sense that the production level of each system is pre-determined and the inputs necessary to achieve that target are subsequently derived. In this way, more than 100 production techniques were generated. This number may seem unrealistically high, but it should be emphasised that when the study is at a stage where regional constraints, aspirations and prices have not yet been defined, only those systems that use more of each input per unit output than any other system can be safely discarded as inefficient.

In general terms the matrix of techniques divides into three levels of intensity, defined by breed, nutrition and prolificacy:

- extensive systems, in which the local fat-tail Awassi breed with net lambing rates from 0.5 to 1.0 lambs per ewe per year is fed on pastures with no or limited use of fertilizer;
- intensive systems, in which Merino crosses with net lambing rates from 1.0 to 1.5 lambs per ewe per year are fed on fertilized pastures and concentrate supplements;
- highly intensive systems, in which Finn crosses with net lambing rates from 1.6 to 2.4 lambs per ewe per year are mainly fed on concentrate feed.

8.5. Management under uncertainty

The matrix of production techniques is the basis for determining long-term strategic decisions in a development context. However, many of the systems defined in the matrix are innovative and there is, therefore, no practical experience on which to base an estimate of their viability and robustness under the regional conditions. Consequently, it was necessary to investigate some of these more carefully in the context of a management environment where short-term, tactical decisions have to be taken in response to the current state of the system and the expected short-term performance. These include decisions on grazing schedules, grazing deferment of paddocks, lamb rearing, supplementary feeding of lambs and cutting of wheat for hay.

For this purpose, criteria for short-term decisions were formulated into appropriate optimization algorithms which were then used to analyse the response to management of a family of sheep and agro-pastoral systems that represented an important group of innovative systems. In this optimization model, a daily time interval for the biological routines and a five-day time interval for the management routines are used. Each run of the model refers to a 21-year simulation, using weather data for the northern Negev from 1962–1983.

The results provide a framework for analysing the relative importance of various management options, the sensitivity of system output to management and the range of economic and biological efficiencies under weather uncertainty and, hence, the feasibility and robustness of the system under consideration.

The results indicate that the pastoral systems under consideration 'look after themselves', in the sense that major differences in economic scenarios only have a small effect on most of the important technical decisions. This is characteristic for complex systems with strong negative feedbacks between components and adds confidence to the applicability of the innovative production techniques that were selected by the interactive multiple-goal planning process.

8.6. Regional development

Development involves the introduction of innovative technologies that use the local and available external resources more efficiently to serve the goals and aspirations of those that have a stake in the sector. In the present context, the possible development pathways within the physical and socio-economic constraints of the region are identified and analysed as an interactive dynamic linear programming problem, based on the matrix of production techniques as discussed above. The production process converts inputs into usable outputs that can be used within the region or traded over the region border. Some inputs, like labour, are available within the region. Others, like concentrates, fertilizers, fencing material and means of transport, have to be bought from outside the region. The main outputs from the agro-pastoral sector are meat and grain. In its most simple form, the economic environment can then be defined by a set of relative prices for these tradable goods.

The constraints relevant to the agro-pastoral sector in a region include the area and quality of the available land, the size of the population that depends on it, the initial endowment of capital goods and the number and breeds of livestock. The rate of accumulation and obsolescence of capital goods as well as the change in flock size and breed composition are slow, and so must be placed within an appropriate planning horizon of at least 15 years.

To evaluate the performance of the model, a regional scenario was defined with boundary conditions similar to those of the northern Negev and optimizations were performed to examine in more detail the course of investments, the generation of revenue for saving and consumption and the dynamics of sheep breed composition in comparison to actual developments. Subsequently, the ability of the model to reflect differences in socio-economic conditions in a realistic way was investigated by analysing developments in three widely differing socio-economic environments that broadly represent the northern Negev in Israel, a region in the western Australian wheat belt and the coastal region of the western Egyptian desert.

The ultimate purpose of these analyses was not so much to find some optimal development path to satisfy a single goal, like the generation of revenue for consumption, but to explore to what extent available production techniques within the physical and socio-economic constraints of the region, can meet various and partly conflicting demands by, for instance, the government, development agencies, various interest groups and the local population. A settlement agency may want to increase the number of settlers, the local population may emphasize their own gainful employment and their own consumptive income, whereas conservationist groups may want to retain extensive pastoral systems and put limits on the use of concentrates and fertilizers. Also, the central government may be concerned about the contribution of the sector to the balance of payment and the World Bank may emphasize control over the inflow and outflow of capital.

An interactive multiple-goal planning procedure was used to analyse perspectives for development in a series of iterations. First limiting values are specified for each of the goals. These are the absolute minimum or maximum values for each goal that are acceptable to the policy maker. Then the maximum attainable value for each goal is calculated while all the other goals are held at their minimum values. In the following iterations, goal restrictions are tightened one by one as the other minimum goal attainment values are improved. The aspirations and the interests of the interactively operating policy maker determine which goals will be tightened and to what degree. In this way, the costs of realizing one goal are expressed in terms of what must be sacrificed on the others. Persons with different aspirations and interests are bound to end up in different corners of the original solution space. Hence, the analyses help to explore perspectives for development and to evaluate alternative options that will affect the resources and technical structure of the sector. The results indicate which technical developments are needed to satisfy the goals and aspirations of the policy makers, but they do not determine what policy measures would be needed to achieve them.

In this way, the decision maker can compare different scenarios for a given region and study their interrelations and consequences. While the selected development pathway may not in fact be implemented in the end, at least the options will have been very thoroughly analysed and some illusions and pitfalls will have been foreseen and, hopefully, avoided. This approach can thus provide a formal bridge between the biophysical and the socio-economic elements of agro-pastoral development and in that way allow for more effective interdisciplinary application of scientific knowledge to arid zone development.