FARMING IN A FRAGILE FUTURE

Economics of land use with applications in the Atlantic Zone of Costa Rica

Robert A. Schipper
PROPOSITIONS

1. The term *land use analysis* should replace *land use planning* (this thesis).

2. FAO’s (1976) *Guidelines for land use planning* put too much emphasis on *land evaluation* and too little on *farming systems analysis*.

3. The FAO (1976) definitions of the different levels of suitability of land units for land use types are economic in character, even for the biophysical part of a land evaluation. Such definitions obscure the technical nature of judgements of agronomists and soil scientists regarding suitability, which are mainly based on yield expectations (this thesis).

4. Linear programming is a useful tool in land use analysis, in particular at the farm and sub-regional level, because it permits incorporation of detailed technological information and facilitates cooperation between agronomists, soil scientists and economists (Hazell & Norton, 1986; this thesis).

5. To assess the comparative effects of changing circumstances or of different policies, good land use analysis requires a distinction of farm types representative of the major farming systems; each should have objective(s) representing the most important behavioural motive(s) of decision makers within a farming system (this thesis).

6. The proposition of Bell *et al.* (1982) that the *aggregation bias* in regional linear programming models is not important in case farm types differ in resource availability but not in technology and objectives, while resources can be exchanged at low transaction costs, is correct (this thesis).

7. Pearce & Turner’s (1990) definition of sustainable development and their related rules for the use of resources are a good starting point for operationalising sustainable land use based on constraint optimisation models (this thesis).

8. *Efficiency* in resource use as defined in the agro-technical or biophysical literature (for example de Wit, 1992; Fresco & Kroonenberg, 1992; Oenema, 1996) is what economists call *productivity*.

9. Conway (1987) incorrectly considers equitability a property of agro-ecosystems. It is a property of the social system in which the agro-ecosystem is embedded (this thesis).

10. For a given structure of land units and land use types, the relative availability of factors of production other than land determines the use of land (this thesis).
11. Abolishing agricultural import levies and export subsidies by the EU benefits farm families outside the EU more than it hurts farm families inside the EU.

12. De *allochtonen*verklaring (Wet bevordering evenredige arbeidsdeelname allochtonen) heeft een ongewenste overeenkomst met een omgekeerde *ariër*verklaring.

The ‘Declaration of foreign origin’ (Law promoting equal participation of immigrants in the workforce of the Netherlands) has an undesirable similarity with an inverse ‘Declaration of Aryan origin’.

13. De beperking van de vrijheid door de Wet op de identificatieplicht vermindert de blijheid.

The Dutch law requiring compulsory identification restricts freedom and decreases happiness.

Propositions presented with the doctoral thesis *Farming in a fragile future: economics of land use with applications in the Atlantic Zone of Costa Rica* of Robert A. Schipper, Wageningen, 13 September 1996.

References


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Economics of land use with applications in the Atlantic Zone of Costa Rica
Promotoren:

dr. A. Kuyvenhoven  
hoogleraar in de agrarische ontwikkelingseconomie

dr. ir. H.A. Luning  
hoogleraar in de landgebruiksplanning voor regionale ontwikkeling in ontwikkelingslanden, Rijksuniversiteit Utrecht
FARMING IN A FRAGILE FUTURE

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Robert A. Schipper
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To Alli

For Merijn
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ABSTRACT

The present study contributes to the search for a methodology for land use analysis, aiming at a land use that provides sufficient (and rising) incomes to the agricultural population and at the same time maintains the productive capacity of land. The contribution focuses in particular on the role of economic analysis.

The study starts with a review of land evaluation and land use planning from an economic angle, providing suggestions for improvement. After a brief examination of prospects for agricultural production and population growth, and problems of land degradation, the concept of sustainable development is discussed. The study opts for a definition of Pearce & Turner (1990). In conjunction with rules for resource use, this definition can be made operational for land use analysis. Reviewing theories of resource economics, it is concluded that these theories are relevant and provide ‘food for thought’, but lack direct or easy applicability to practical cases of land use analysis. Concepts of cost-benefit analysis and of farm management, production economics and household economics are more directly applicable to land use questions. Other important concepts originate from regional economics, or point to institutional problems, in particular questions around land tenure and contradictions between land users. ‘Unsolved’ problems within the discipline of economics, should caution against undue belief in the approximation of reality of the results.

The role of economics within land use analysis is outlined. The background to this outline is formed by a skeleton model of the agricultural sector, concepts of regional agricultural planning, in particular a comprehensive resource based approach, and the so-called LEFSA sequence for land use planning. The basic idea is to distinguish levels of analysis and to consider the analyses made by several disciplines (including agronomy, soil science and economics) at each of these levels. Furthermore, at each of these levels models can be designed, which are connected in a modular fashion and which foster multi- or interdisciplinary collaboration. It is advocated that the term land use planning be replaced by land use analysis.

Linear programming models as a tool for land use analysis are discussed. A linear programming model for a case study, the Neguev settlement in the Atlantic Zone of Costa Rica, is presented. The matrix of the model includes five sub-matrices each encompassing a different farm type. The farm types are distinguished on the basis of land-labour ratios, considering three soil types. Land use activities are included in the form of Land Use Systems & Technologies. These represent land use systems with fixed input-output coefficients. Two indicators for sustainability are taken into account: soil nutrient depletion and biocide use. These are built into the model via constraints, marking upper limits to the use of renewable resources and to the waste flow into the environment. The linear programming model forms part of the USTED (Uso Sostenible de Tierras En el Desarrollo) methodology for land use analysis.

Several land use scenarios are analysed to assess whether incomes of farms can increase through an improved, more sustainable, land use. A base scenario is calculated to serve as a reference for assessing the impact of policy measures or changing socio-economic conditions. A striking feature of the base scenario is the large area with palm heart in comparison to the actual area. Doubling the biocide price hardly affects its use, while a quantitative restriction on the use of biocides to half the amount used in the base scenario reduces average incomes by less than 1%. When soil nutrient depletion is restricted to ‘critical losses’ per year over a ten year period, average incomes are reduced by less than 3%. Other scenarios concern the impact of decreasing palm heart prices, the influence of increasing wages and the role of the discount rate. Given a certain structure of land use types and land units, land use is determined by the costs and availabilities of other factors than land; in the Neguev case labour.
The origin of this study can be traced back to 1981. I participated in a research project of the Department of Development Economics of the Wageningen Agricultural University with the Agrarian Research and Training Institute (ARTI), Colombo. The project studied regional agricultural development planning in Sri Lanka and became interested in issues surrounding present and potential land use. This was followed up after I returned to Wageningen to work at the Department of Development Economics and intensified during missions to Kenya (1985 & 1986) and Ethiopia (1987). It culminated after 1986, when the Wageningen Agricultural University started the Atlantic Zone Programme (AZP) in Costa Rica, in collaboration with the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) and the Ministerio de Agricultura y Ganadería (MAG), both in Costa Rica. The research for a methodology for land use analysis between 1990 and 1994, together with Jetse Stoorvogel and Don Jansen, both of the AZP programme, formed the decisive input which enabled me to finish the present study. Thank you both for this interdisciplinary cooperation. It was excellent and provided a lot of inspiration. I return to the Atlantic Zone Programme below.

The basis of my training as an agricultural economist was laid earlier during my study in Wageningen. Many people contributed, but I would like to single out five in particular: Prof. dr F.P. (Frans) Jansen for his clear lectures on (agricultural) development and the use of mathematical programming; the late Prof. ir A. (Anton) Franke for his wise mixture of theory with practice in agricultural development; Henk Luning for his instruction in farm management (research) and his stimulating guidance during my MSc-thesis on the evaluation of agricultural research. During my praktijk睇ijd (stage) in Surinam Cees Houtman showed me how to organise and analyse farm surveys. Finally, I still remember the inspiring lectures of the late Prof. mr A.H. Ballendux in agrarian law and land tenure. Lessons for life!

After Surinam, I made a year-long trip with a friend, Berry van Gelder, to visit development projects in Latin America, Australia and Indonesia. Apart from a tremendous experience, it revealed new worlds to me and provided an insight into the realities of development cooperation.

Joining the research group ‘The Small Farmer and Development Cooperation’ of the International Agricultural Centre in Wageningen opened new avenues to me: a much broader insight into problems of
farmers in developing countries, a conviction that interdisciplinary work is important and many friendships. I would like to thank Willem Oosterberg for his support and for his continuing interest into the well-being of each member of the group. Together with another member of this group, Paul Engel, I was able to participate in a team studying the impact on the income of farmers of a Dutch project for improving tobacco cultivation in Tarapoto, Peru. Apart from gaining experience in farm level data collection and analysis, it taught me that institutional and market issues are as important for land use decisions as technological innovations through research and extension.

In Panama, working for a FAO project on agricultural sector planning, I was able to become acquainted with such planning. Luis Riffo also showed me Chilean examples and introduced me to theories of the Instituto Latinoamericano de Planificación Económico y Social (ILPES), Rogerio Porto made me aware of objectives and strategies, while Juan Pacheco demonstrated the possibilities of linear programming at the sector level.

From sector planning back to farm level research. At FAO headquarters the late Neil Carpenter showed me the importance of obtaining a good understanding of farming systems before attempting an intervention. John Dixon and Michel Gauchon involved me in the design of a farm analysis package for a smooth and standardised collection and analysis of farm survey data. This was to be very important in setting-up my later farm surveys in land use studies.

In Sri Lanka I was back again in agricultural planning, this time at the regional level. Sien Thio and Frank Polman of the Department of Developing Economics and Sam Samat of ARTI introduced me to resource based planning and the role of land use studies and land evaluation. With Gamini Wicremasinghe and Madavi Malalgoda, both of ARTI, I collected data in Ratnapura, first at the district and lower administrative level, later at the village and farm level. The main aim was to understand present land use choices, including technology.

Through participating in the Training Project in Pedology in Chuka, Kenya, I became engaged in issues around soil surveys and land evaluation, explained to me by Titus de Meester en Joost Dijkerman. Such involvement was stimulating for my further interest in land evaluation, but also made me aware of the limitations of land evaluation.

In 1986 the Atlantic Zone Programme in Costa Rica started. As mentioned above, I enjoyed very good cooperation with Jetse Stoorvogel and Don Jansen in our search for a methodology for land use analysis. The present study describes the methodology, named USTED (Uso Sostenible En el Desarrollo). Of course, the development of USTED is
also based on the contributions of many other people, in particular Johan Bouma, Louise Fresco and Salle Kroonenberg in Wageningen, and Robert Sevenhuysen, coordinator of the AZP from 1990 to 1994. The contribution of Hans Jansen, the present coordinator is gratefully acknowledged too. USTED is also based on the research of the AZP between 1986 and 1990, due to the efforts of Fred van Sluys, Henk Waaijenberg and Willem Wielemaker. The energy put in by both Jan Wienk (first coordinator) and Hans Bronkhorst (second coordinator) was highly motivating. Finally, much credit must be given to the many students who, who through their fieldwork or thesis research contributed to the research. In particular, I would like to mention Jogchem Finnema, Paul van den Berg, Roald Droog and Joris Akkerman, who all did excellent work for the farm level data collection during 1991 and 1992.

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Together with Olaf Erenstein, I developed a linear programming model to analyse land use in the Matara district of Sri Lanka. This model can be seen as a predecessor of the present model. Cornelis Verschoor assisted with the translation of the Matara model from one software package (XA) to another (OMP). Their endeavours are very much appreciated.

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Sara van Otterloo Butler edited the manuscript with regard to the use of English. The present final version is certainly better than the draft one!

Edmundo Arce Díaz in Costa Rica prepared a Spanish translation of the summary, which was revised by Gerard Verschoor. Both are very much thanked for their efforts. Jan Willem Nibbering revised the Dutch translation. It became better Dutch, for which I am very grateful. Of course, I am responsible for the content of both translations.
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1 INTRODUCTION

Subject

In recent times various concerns about present and future land use have been expressed. Are the land (and water) resources of the earth able to supply sufficient products (food and other) to sustain a growing population and provide the agricultural population with increasing incomes? Will land and water resources be able to maintain their productive capacity over time, and provide sufficient living space and environmental amenities? Answers to those questions range from pessimistic (e.g. Brown & Kane, 1995) to optimistic (Penning de Vries et al., 1995). The pessimistic answer is mainly based on extrapolating present trends of population growth, and of agricultural production and productivity, while the optimistic one is based on comparing population trends with what could potentially be produced by land and water resources in different regions of the earth. Land use analysis as defined in the present study could bridge the gap between these two approaches for particular areas.

Since the times of Ricardo and Malthus, the problems of feeding the population of different areas and thus of land use have been an explicit concern of economists. Within economics, land economics developed as a special branch studying land resource use from different perspectives. Nowadays, the study of land use is part of agricultural economics.

Obviously, land use is also the focus of more technical disciplines like agronomy and soil science. As a result, a separate branch of study developed involving a multidisciplinary assessment of the capability of land for different uses, usually called land evaluation (FAO, 1976 & 1983). Dent & Young (1981: 115) describe land evaluation as "the process of estimating the potential of land for alternative kinds of use". Ideally, such an assessment also incorporates economic and social aspects. Besides land evaluation, comparable approaches to the identification of potential land uses exist. An example is the land capability classification (Klingebiel & Montgomery, 1961), principally guided by the need for soil conservation. Originating in the USA for farm planning, it finds application in a number of developing countries.

Land evaluation is usually the basis for land use planning (FAO, 1993a). The latter can be loosely described as the allocation of different tracts of land to different uses, aiming at the best land use. 'Best' is
usually defined from a human point of view, involving objectives, options and constraints.

Land use issues are also addressed in the context of development projects and programmes, in particular concerning regional agricultural development, or, for example, medium- to large-scale irrigation projects. Some of these projects make use of land evaluation or comparable approaches to ascertain the agricultural potential of the land.

The present study contributes to the search for a methodology for land use analysis, aiming at a land use that provides sufficient (and rising) incomes to the agricultural population and at the same time maintains the productive capacity of land. It focuses in particular on the role of economic analysis and addresses the following major research questions.

1) How useful are present approaches within land evaluation and land use planning for analysing land use from an economic point of view? To what extent can they be improved?
2) Economics is rich in different theories; which ones are relevant and how can these theories be used for analysing land use issues?
3) What are the main elements of an economic analysis of land use? What form should collaboration with other relevant disciplines like agronomy and soil science take?
4) What is the role of linear programming within a methodology for land use analysis? Should it be confined to exploring future options?
5) How can sustainability issues be incorporated into land use analysis and in particular into linear programming models, serving as a tool for such an analysis?

Plan of study

After explaining the principles of land use planning and land evaluation in Chapter 2, an economic critique of land evaluation is given. Economic theories of land use are presented in Chapter 3. Land as an economic resource is defined and related to concepts of sustainable development. This is followed by theories of resource use, cost-benefit analysis, and farm management, production economics and household economics. Finally, a number of other areas within economics, which are relevant for land use, are briefly presented.

Current methods of land use analysis and planning are reviewed in Chapter 4. After presenting a skeleton model of the agricultural sector, regional agricultural planning is outlined in order to provide a background for land use planning. The role of land evaluation and farming systems analysis in studying land use issues is explained. This is followed by some suggestions for improving land evaluation as a method.
Introduction

from an economic point of view. Finally, a methodological approach to land use analysis is outlined in which different levels of analysis (land use system, farm, (sub-)region) are distinguished. For each level appropriate models are presented. Emphasis is placed on the links between levels and the need for coordinated and relevant contributions from different disciplines, in particular from agronomy, soil science and economics. In view of possible aggregation biases, grouping of farm systems is recommended.

For the farm and sub-regional level, the use of linear programming models is reviewed in Chapter 5. At these levels, linear programming allows the incorporation of detailed agronomic and pedological data into economic analysis. Hence, it is conducive to interdisciplinary collaboration. Formulation of land use activities with fixed input and output coefficients is close to common ways of thinking of many farmers about crop cultivation and livestock keeping. Furthermore, the three central components of linear programming, objective function, variables (options) and constraints, connect well with the basic idea of land use planning, i.e. the allocation of different tracts of land for different uses aiming at the best land use. Lastly, a linear programming set-up allows environmental concerns regarding resource use and pollution to be incorporated fairly simply. This in turn permits an (economic) analysis of land use sustainability.

Linear programming also has disadvantages. In the first place, non-linear relations (e.g. most production functions, economies of scale) cannot, or only with difficulty, be accommodated. Secondly, linear programming is a normative approach, making it less suitable for explaining actual land use. That is why the models presented here are mostly used for exploring future options, while non-linearities are circumvented by linear approximations (production functions). A third point is that objective function coefficients are taken as given in linear programming. As a consequence, the models in the present study have exogenous product and factor prices. This is only tenable at the farm- and sub-regional levels of analysis. At higher levels several prices have to be considered endogenous, which would require complex adaptations. Finally, although the variables in linear programming are continuous, the feasible area, formed by the hyperplanes of constraints, has a non-smooth (kinky), and thus non-differentiable outer bound, with a finite number of corner points. This outer bound defines the production possibility frontier. Depending on the coefficients of the objective function, one of the corner points is usually the optimal solution. The form of the feasible area leads to ‘jumpy’ behaviour where prices or resource availabilities change.
In Chapter 6, the linear programming approach is elaborated into a model for a case study, the Neguev settlement in the Atlantic Zone of Costa Rica. The model incorporates both the farm and the sub-regional level. Through the study of different scenarios, the effects of changing land use determinants or different policies regarding land use, farm incomes and the environment can be assessed. This is done in Chapter 7. The study ends with a discussion and conclusions regarding the proposed approach for land use analysis.

New elements

The present study aims at contributing to the development of a methodology for analysing land use problems and possibilities, in particular the economic aspects of such a methodology. The methodology, designed in collaboration with the Atlantic Zone Programme in Costa Rica was baptised USTED (Uso Sostenible de Tierras En el Desarrollo, Sustainable Land Use in Development). The methodology has a modular character, and each module is connected through the exchange of data (Stoorvogel et al., 1995). The methodology is supported by a set of software modules, MODUS (MOdules for Data management in USted). The methodology distinguishes between levels of analysis: land use system, farm and sub-regional level, while recognising the influences of events at higher levels of analysis.

One module of this methodology is a linear programming model, named REALM (Regional Economic Agriculture Land-use Model), designed to analyse land (and labour) use choices in view of farm level objectives, taking into account both farm level specific constraints and constraints at the sub-regional level. The constraints at the farm and sub-regional level not only refer to the limited availability of factors of production (land and labour), but also to environmental factors (depletion of soil nutrients and use of biocides). Economic farm level objectives, in particular farm income, steer the solution process of the model as farmers are the ultimate decision makers regarding land use.

The linear programming model permits the incorporation of technical details. This is possible because the model is set up for a small area, a sub-region. Given restrictions of time and person-power for analysis (as well as software and hardware limits), such a detailed approach would be less suitable or desirable for higher levels of analysis.

The linear programming approach to land use analysis is suitable for the incorporation of sustainability issues. Using the definition of Pearce & Turner (1990) of sustainable development as a starting point, rules of resource use are related to certain constraints in the linear programming
model. Sustainability parameters are designed, which are relevant to the case study area. The left hand side of these constraints represents the use of a resource (or the amount of pollution), while the right hand side is indicative of the natural rate of regeneration in the case of a renewable resource, or of the assimilative capacity of the environment in the case of a pollutant. This way of formulating permits the analysis of trade-offs between economic objectives and environmental constraints. Under the conditions found in the case study area such trade-offs, comparing a base scenario with environmental policy scenarios, indicate that environmental gains are possible without affecting the level of income by much. Furthermore, through comparing a version of the model indicative for the present agricultural technologies with the base case, the analysis shows that considerable improvements in income as well as of the environment are possible, when technical advancements are introduced.

In distinguishing between the farm and the sub-regional level of analysis, an effort was made to diminish possible aggregation bias by grouping farms into farm types, clustered on the basis of proportional availability of land and labour resources. However, as all farm types can choose from the same land and labour activities with the same returns, and labour can be freely exchanged between farm types, the aggregation bias turns out to be small. Nonetheless, distinguishing farm types under these conditions still provides an understanding of the differences between farm types with regard to land use and income distribution aspects.

By way of an appetiser: three points

In this study, an economic critique of land evaluation is formulated, in particular with regard to the definition of land use types and the use of suitability definitions (FAO, 1976, 1983 & 1993a) that are economic in character (benefits are compared with costs). As such, it is commendable that non-economists are keen to incorporate economic considerations in their assessment of land use potential. However, in this case the current definitions obscure the technical nature of the judgements of agronomists and soil scientists regarding land use types and their suitabilities, which are mainly based on yield expectations. Besides, quantitative input and output data of land use systems can never be the sole basis for economic judgements regarding the relative attractiveness of land use systems.

Second, the present study recommends replacing the term land use planning with land use analysis. Land use planning, normally executed at (sub-)regional or higher levels has a tendency to prescribe the ‘best’ land use, and carries a connotation that decisions can be made about land use at these levels. This is hardly ever the case. Land use decisions are
mostly taken at the farm level. Of course these decisions can be influenced by decisions at the (sub-)regional or national level. Proper decision making regarding land use policies requires a thorough analysis of possible land use decisions at the farm level. Such an analysis is a major aim of land use planning. Therefore, land use analysis is preferred over land use planning.

Finally, a major conclusion from the comparison of the different scenarios will be that, given a certain structure of land units and land use types, land use is determined by the costs and availabilities of other production factors than land. In the Neguev case it is labour, but in other cases it could have been capital as well.
2 LAND USE PLANNING AND LAND EVALUATION

2.1 Land use planning

The analysis of the agricultural sector of a country and the planning of its future development has been approached from a macro-economic and sector perspective, and from a micro-economic point of view. Traditionally, the first is more demand-oriented and in a way 'top-down'. The latter is supply-oriented, resource-based and more 'bottom-up'. Notwithstanding the orientation, both approaches look for a balance between the demand and supply of commodities. In the present study, the micro-economic approach will be examined in the context of the agricultural sector of a region within a country. This is in line with the conceptual framework of Sadoulet & De Janvry (1995: 5), in which "the analysis of the economy and of policy options is progressively built from the microeconomic analysis of consumers, producers and households to the partial equilibrium analysis of single markets, sectoral policy analysis, macroeconomic analysis, and the links between these different levels of policy analysis". However, here the emphasis is on the supply of agricultural commodities by producers using (natural) resources, taking into account constraints to sustainability in a regional context.

The macro-economic approach deals with aggregated parameters such as the demand for and the production of commodities, the investment level in agriculture, and the utilisation of fertilizer at the sector level (Moll & Schipper, 1994). Relationships between the parameters of the agricultural sector and those of other sectors of the economy are referred to when setting out guidelines for national policies generally aimed at increasing production and welfare. Mollett (1990) provides a good example of a non-model approach to this type of planning. Thorbecke (1982) outlines agricultural sector analysis with emphasis on the use of different types of models, while González et al. (1977a & 1977b) provides a complete framework for planning of agricultural development, based on a systems view of planning, as well as on the notion of a benevolent yet powerful government, capable of controlling the agricultural sector. In the macro-economic approach to agricultural planning there is limited scope for including the varied and specific production circumstances of agriculture into the analysis.

The micro-economic approach, because of its orientation on the supply side of agriculture, deals with farm households and their production
circumstances in specified locations to determine potentials and constraints for improved production and welfare of the households. Relationships of farm households within the regional situation are part of the analysis, but the national context remains outside the scope of the micro-economic approach; in a way it is taken as given. In the present study, this approach will be presented in the context of the agricultural sector of a region within a country. The agricultural sector of a region functions within the economy of a region as a whole, and analysis and planning of the agricultural sector of a region can be placed within a more general type of regional planning. Regional planning is briefly introduced in Appendix 1. However, specific emphasis on the agricultural sector in a region is justified for those regions where agriculture forms the main occupation of a large part of the population and in view of the special characteristics of agriculture.

As outlined above, the micro-economic approach to regional agricultural planning is based on the potential of the natural resources of a country (Moll & Schipper, 1994). The potential is estimated on the basis of data and judgments with regard to the possibilities of land and water, plants and animals, and in relation to its present use. Part of the planning process is meant to indicate which potential uses of natural resources have to be assessed, and how the results of such an assessment can be used. In this process complementary factors of production (management, labour, capital), commodity inputs and outputs, markets and prices, and institutional factors are also taken into account; as well as the objectives at different levels and of different groups in the society. Such a type of planning can be called comprehensive resource-based (regional agricultural) planning (ARTI/WAU, 1981; Polman et al., 1982; Schipper, 1983; and Moll & Schipper, 1994); for more details see Section 4.2. If the basic object of this type of planning is the use of the natural resource land, it is called land use planning.

Following Fresco et al. (1992: 10), land use planning is considered a form of (regional) agricultural planning. It is directed at the 'best' use

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1 Land use (planning) as such also involves, of course, other uses than agricultural ones, for example roads, or tourist, industrial and urban sites (Fresco et al., 1992: 10). However, given the agricultural background and context of the development of land evaluation and of farming systems analysis, it is practical to restrict land use planning in this research proposal to agricultural (and forestry) uses. Furthermore, it is impossible to plan the use of land in isolation. Land use implies at the same time the use of labour and capital. Therefore, regional agricultural planning would be an even more correct term than land use planning. However, in view of the acceptance of the term land use

(continued...)
of land, in view of accepted objectives, and of environmental and societal opportunities and constraints. It is meant to indicate what is possible in the future with regard to land use (potentials) and what should be done to go from the present situation to the future one, in other words, how to change land use. In a similar sense, Dent (1988: 183; Fifth Draft of the FAO's *Guidelines for Land Use Planning*) defines land use planning as "A means of helping decision-makers to decide how to use land: by systematically evaluating land and alternative patterns of land use, choosing that use which meets specified goals, and the drawing up of policies and programmes for the use of land." The definitive publication of the *Guidelines for Land-Use Planning* (FAO, 1993a: 86-87) suggests a comparable definition: "The systematic assessment of land and water potential, alternative patterns of land use and other physical, social and economic conditions, for the purpose of selecting and adopting land-use options which are most beneficial to land users without degrading the resources or the environment, together with the selection of measures most likely to encourage such land uses."2

Fresco *et al.* (1992: 10-11) provide the following background to land use planning:

"At one time land use planning took place for areas that were 'empty'. Nowadays these 'empty' areas, for which (re)settlement projects may be designed, are disappearing rapidly. Reclaimed areas are another category for which settlement plans can be made. However, in the majority of cases, land use planning is practised for areas which are already used in one way or another. Change from the present land use to a projected, presumably improved, land use can only be achieved gradually with the participation of the users of the land. As the users of land are in most cases farm households with specified rights to (the use of) the land, it is difficult and (perhaps) undesirable to enforce changes. It is better to stimulate changes, by creating the proper infrastructure and incentives3.

1(...continued)

planning, it will be used here. Notwithstanding, for reasons provided in Sections 4.2.3 and 4.5, the term land use *analysis* is preferred to land use *planning* for the research described in Chapters 5 to 7.

2 The definition continues: "Land-use planning may be at international, national, district (project, catchment), or local (village) levels. It includes participation by land users, planners and decision-makers and covers educational, legal, fiscal and financial measures."

3 Of course there are examples in which land use changes are enforced: the establishment of plantations in colonial times, the collectivization of Soviet agriculture, (continued...)

Land use planning, therefore, does not end at the stage of indicating the best use of land, but should include formulation of all types of measures to be taken by those involved in the use of land to achieve the desired use of land. These measures could include investment in land, for example irrigation. Land use planning aims at the identification of projects, programmes and policies to reach the desired changes.

In each particular situation, specific objectives are required. In general, they include efficiency of the use of scarce natural resources, equity between groups in the society with regard to the distribution of the benefits and costs of the use of those resources, and conservation of those resources for future use. Between those objectives there are often conflicts and trade-offs. It is also likely that there will be conflicts between different groups of land users about the distribution of the benefits and costs of the use of land (Blaikie, 1985; FAO, 1989; Riddell, 1985). Examples of such groups, each with their own goals, are land owners and tenant farmers, big and small farmers, and commercial plantation owners and adjacent subsistence farmers. The goals of the different groups may also be different from ‘national’ objectives as formulated by the government. As a result, governments often disagree with farmers over the best use of land. Another source of disagreement could originate from differences between analyses based on private economic and financial considerations and analyses from national economic and/or social points of view, see, for example, Helmers (1977), Gittinger (1982) and Kuyvenhoven & Mennes (1985).

In economics, an assumption would be that an objective of using a given unit of land is to produce a surplus of benefits over and above the costs of land use. The relative ability of a certain land unit to produce a surplus can be called its ‘land use capacity’ (Barlowe, 1986: 12). In general, land use capacity has two components: ‘accessibility’ and ‘resource quality’. "Accessibility involves the convenience, time and transport costs savings associated with specific locations with respect to markets, shipping facilities, and other resources. It is concerned with optimizing transportation and communication costs and time-distance considerations. Resource quality involves the relative ability of a land resource to produce desired products, returns or satisfactions. With agricultural lands, quality is usually viewed in terms of native fertility or

3(...)continued)
the establishment of communes in China, and the movements of farmers into planned villages in Tanzania and Ethiopia.

4 Benefits and costs should be interpreted as generic terms for, respectively, contributions to and deductions from an objective. Also, objectives in economics refer to more than 'profit maximisation', for example, food security, maintaining the farm enterprise in the long run, and work satisfaction.
fertility in combination with ability to respond to fertiliser inputs. Quality may reflect climatic advantages - favorable temperature and precipitation levels, low wind velocity, or infrequency of storms." (Barlowe, 1986: 12).

Land evaluation, especially the biophysical part of it, is a tool to assess the resource quality, as well as, in part, the accessibility components of the land use capacity, where land use capacity is referred to as 'land suitability'.

2.2 Land evaluation

Land evaluation is a multidisciplinary tool for assessing the suitability of land for different uses. The main units of analysis are land units and land use types. The area of a region is subdivided into homogeneous land units, at least more homogeneous than the region as a whole. Each land unit is evaluated with regard to its suitability for a number of pre-selected land use types, e.g. maize, bananas, dairy cattle, extensive grazing. The land use types have certain requirements (which could be called growth factors needed for - demanded by - land use types in order to grow successfully), while the land units have certain qualities (properties which characterise the land unit), which can be supplied to the land use types. By comparing the requirements with the qualities, the suitability of land use types for land units is assessed. This process is called 'matching'.

5 Land suitability is defined as the fitness of a given type of land for a specified kind of land use (FAO, 1983: 227).

6 Land unit: an area of land demarcated on a map and possessing specified land characteristics and/or qualities (identical to land mapping unit, FAO, 1976: 82).

7 These suitabilities can be assessed with and without improvements in land, if such improvements, through investments, appear attractive.

8 Land use type: a kind of land use described or defined in a degree of detail greater than that of a major kind of land use {FAO, 1976: 83; in fact, the concept land utilization type is defined, but this is the same as a land use type, see FAO (1983: 228)}. See also variants on this definition in FAO (1983: 228) and in FAO (1993a: 87). In the present study land use types are defined somewhat differently, in line with Fresco et al. (1992: 164-165), see Sections 2.3.2 and 4.4.

Major kind of land use: a major sub-division of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, recreation.
In general two parts can be distinguished in land evaluation procedures. The first part is an ecological evaluation in which the suitability of land use types is assessed only with regard to physical and biological factors. The main objective is to reach conclusions about the physical productivity and the sustainability of the proposed land uses. The second part is an economic evaluation of the land use types, including a cost-benefit analysis of proposed investments in land, and is based on economic and social factors, as well as government policies. Thus land evaluation assesses whether land use types are viable and attractive from different points of view.

During the last decennia, soil scientists have tried to formulate how physical and biological data on land and its use can be converted into indications for land use planning, with regard to the relative attractiveness of different land uses. This culminated in *A Framework for Land Evaluation* (FAO, 1976). More details can be found in FAO (1983, 1984a, 1985 & 1991). The framework was a step in the right direction, but several objections from an economic point of view can be made (see Section 2.3). For objections from non-economic points of view, see, among others, Van Diepen (1983), Van Diepen *et al.* (1990) and Fresco *et al.* (1992).

Fundamental principles in the suitability assessment in land evaluation (Fresco *et al.*, 1992: 19) are:
- selected land use types must be relevant to national/regional development objectives as well as to the physical, economic and social context of the area concerned;
- land use types are specified in terms of socio-economic and technical attributes, and in terms of requirements;
- evaluation involves the comparison of two or more land use types;
- land suitability refers to use on a sustained basis;
- suitability assessment includes a comparison of yield (benefits) and inputs (costs); and
- land evaluation requires a multidisciplinary approach.

Land evaluation supports land use planning by supplying alternatives for land resource use and by providing for each alternative, information on yield and input levels (and/or benefits and costs), management, needs for infrastructural improvements and effects of the land use on the environment (on-site or off-site)(Fresco *et al.*, 1992: 19). Decisions on desirable land uses or land use changes and the planning of interventions in the form of policies, programmes and projects to implement such land

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uses or land use changes, are part of the (land use) planning process. Land evaluation specialists should be involved in the integration of land evaluation results into this process (Fresco et al., 1992: 19).

The overall land evaluation procedure includes the following steps, (Fresco et al., 1992: 23-24, after FAO, 1984a; see also Dent & Young, 1981; McRae & Burnham, 1981; and van Lanen, 1991; the steps are illustrated in Figure 2.1):

1) Selection and description of land use types which are relevant to policy objectives, the development objectives as formulated by planners, and to the overall socio-economic, land use and agro-ecological conditions in the area.

2) Determination of the land use requirements of each of the selected land use types.

3) Delineation of land (mapping) units based on the results of land resource surveys (climate, landforms, soils, land use, vegetation, surface and groundwater). Each of these land units has a number of characteristics such as slope, rainfall, soil depth, drainage, vegetation cover, etc., in which it differs from neighbouring land units.

4) Translation of the characteristics of each land unit into land qualities such as the availability of water and nutrients, the resistance to erosion, etc., which have a direct impact on the performance of the selected land use types.

5) A 'matching' process in which the requirements of the land use types are compared with the qualities of each of the land units. This leads to separate suitability classifications of the land units in physical terms, for each of the land use types considered. Suitability classes express the relative fitness of a certain land mapping unit for a selected land use type. Suitability classes may refer to current land conditions, or, when land improvements are considered in the evaluation, to suitabilities after the implementation of these improvements.

6) An analysis of possible environmental impacts of land use changes that might be implemented on the basis of the results of the land evaluation; and, depending on its objectives, the expression of land suitability classes in monetary terms.

Applying land evaluation as suggested in this section could provide an insight into the biophysical as well as socio-economic potentials of different land uses in a region. However, land evaluation is a tool with positive and negative elements and can thus be criticised. This can be found in the next section.
Figure 2.1  Land evaluation procedures
2.3 An economic critique of land evaluation

Land evaluation can be criticised on different grounds. From an economic point of view the following remarks are pertinent.

2.3.1 Selection of land use types

As a first step in a land evaluation, a decision needs to be taken about which land use types to consider for evaluation. Several criteria are usually taken into account, such as present land use, uses which might possibly have good agronomic prospects considering rainfall and temperature (preferably based on research-tested information), and uses for which market prospects appear to be good. As the evaluation should be manageable, not too many land use types can be considered. At present, no proper methodology for selecting land use types exists. As the FAO (1976) definitions of suitability levels are economic in character (see Section 2.3.3), the danger of implicit economic judgments in selecting land use types is present.

2.3.2 Comparing land use types with cropping and livestock systems and with economic activities

A second problem is the definition of land use types in relation to farm systems. In general, land use types are part of farm systems. The consequence is that land use types are not independent. However, how the relationships between land use types should be taken into account in the suitability assessment is less clear; linear programming models, which can take into account input-output relationships between land use types as well as common resource use, are a possible approach (Chapters 4, 5 and 6). Furthermore, there is no agreement whether land use types should be defined in a broad way (e.g. irrigated crops, thus as a major kind of...
land use, see note 8, or even as a combination of a farming system and a kind of land use\textsuperscript{12}, or in a narrow way (e.g. paddy). The first is too broad for proper evaluation, while the latter easily leads to too many land use types for evaluation, especially, if different levels of technology are distinguished (e.g. IR-36 paddy with recommended application of fertiliser and pesticides).

At the farm level, it seems useful to equate land use types with cropping or livestock systems. This would provide a link with a theory of farming systems. A farm can be seen as a system\textsuperscript{13} (for the concept of systems, see Section 3.2.5) and then defined as follows:

- works in a societal (socio-economic) and environmental (biophysical) space which changes and is changed;
- consists of subsystems like:
  - cropping system(s),
  - livestock system(s),
  - household system(s);
- is managed by decision makers like farmers (or other household members); and
- converts, within subsystems, inputs\textsuperscript{14} into outputs under changing levels of technology which affect the input-output relationships.

The link of land use types with cropping/livestock systems as components of farm systems provides a possibility to incorporate in the suitability assessment the phenomenon that land use types are part of a farm. Farms, typically, have multiple objectives and scarce resources, which can be allocated to alternative uses. In economic terms these uses are often called enterprises or activities. If enterprises, activities, cropping and livestock systems, and land use types were considered as

\textsuperscript{12} See, for example, Luning (1973: 15) in which one of the land use types is indicated as "Small holder rainfed arable farming, traditional technology." Also, De Jong (1976) provides such examples as "Small holder rain-fed mixed farming, intermediate technology." As the components of farming systems, crops, livestock, (i.e. land use types proper), have different requirements, farming systems as a whole cannot be evaluated by land evaluation, only the individual land use types.

\textsuperscript{13} A farm system as defined here, is often called a farm household system (FAO, 1990: 15), see also Fresco \textit{et al.} (1992: 162). See also note 54 in Section 4.1, for a comparable definition.

\textsuperscript{14} Inputs include here factors of production such as labour, capital and land. This provides another link with land evaluation. Farms possess parts of land units, often called parcels, with the same qualities - in a land evaluation sense - as these land units (see also Section 4.1, note 54).
more or less the same, it would clarify the relations between land evaluation, farming systems analysis and economic analysis as tools for studying agricultural development. Equating land use types with cropping and/or livestock systems enhances the relations between land evaluation and farming systems approaches at the farm level. This relation could benefit both approaches: land evaluation can benefit by properly taking into account the on-farm relations between land use types, and by making use of the research component of the farming system approach, if necessary. Farming systems analysis can benefit through the emphasis of land evaluation on the suitability of land units (as parcels of farms) for land use types, in other words, on taking into account environmental factors, and its emphasis on potentials in this regard.

However, the above remarks do not solve all problems between land evaluation and the farming systems approach. The strength of land evaluation lies in the independent evaluation of separate land use types, as this simplifies reality to a manageable level, as well as in its ability to evaluate land use types at a higher level than the farm. In this way the results of land evaluation are often more usable for land use planning. Apparently, there is a trade-off between a 'larger scale' approach (farming systems analysis) and a 'smaller scale' approach (land evaluation). Fresco et al. (1992: 39-40 & 50-51) emphasise that both farming systems analysis and land evaluation can be applied at all relevant levels: national, (sub-)regional, farm, and activity.

### 2.3.3 Suitability definitions/levels

Another problem is the definition of suitability levels. In the FAO framework, definitions of suitability levels are expressed in economic terms, comparing costs and benefits of each land use type on each land unit. Results of an ecological evaluation, exclusively based on physical

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15 Of course, there are minor differences between those concepts. For example, a cropping system includes the soil on which the crop is grown, while in the definition of a land use type the soil is excluded, as it is part of the land unit on which it is grown. However, see Van Diepen et al. (1990) for a qualification of this point of view. In Section 4.4 the concept of land use type is elaborated; combined with land units, they form land use systems (see Section 4.1).

16 For an example of such an approach, see Schipper (1988).

17 Scale in a cartographic sense; large scale means more detailed, e.g. 1:10.000; small scale means less detailed, e.g. 1:100.000.
and biological factors, are therefore difficult to retrace. Also dangerous are all sorts of implicit economic assumptions which are blurred in the final evaluation and report. Examples of land evaluation studies in which this occurs are Beek & Bennema (1974), Grupo de Avaliação de Terras (1980), Wielemaker (1982), Dent & Ridgeway (1986), FAO (1984b) and Van Lanen et al (1981). Moreover, 'economic' definitions of suitabilities are still advocated, see FAO (1993a: 40).

As a result of the matching, a suitability classification is obtained, in other words how suitable a certain land unit is for a certain type of use. In principle this applies to all land units of an area and to all land use types. Commonly, the following gradations are used:

- **S1**: highly suitable;
- **S2**: moderately suitable;
- **S3**: marginally suitable;
- **N1**: currently not suitable; and
- **N2**: permanently not suitable.

FAO (1976: 22-24) gives the following definitions of these gradations.

- **Class S1** Highly Suitable
  "Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level."

- **Class S2** Moderately Suitable
  "Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land."

- **Class S3** Marginally Suitable
  "Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified."

- **Class N1** Currently Not Suitable
  "Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner."

- **Class N2** Permanently Not Suitable
  "Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner."

Careful reading of the definitions reveals that the wording of suitabilities is not in biophysical terms, but is economic and in principle relates benefits to costs. As such, it is commendable that the soil scientist community has realised that the choice between different land uses is
strongly influenced by economic factors. However, for the biophysical evaluation, definitions are required in terms relating biophysical inputs to biophysical outputs. In the second part of the evaluation, an economic analysis (taking into account the farm, regional and national socio-economic contexts) can be made of those biophysical input-output relations. Biophysical, sometimes called ecological, suitability definitions have been used, for example, in Veldkamp (1979), Dimantha & Jinadasa (1981: 32), Wood & Dent (1983), Bruggemans & Cools (1986), Smaling (1986) and De Visser & Dijkerman (1988). The reader is referred to Section 4.4 for a discussion of such suitability definitions. Some authors use economic suitability definitions in line with the original FAO (1976) definitions, but grade according to a ‘(land) productivity index’ relative to a calculated ‘potential’ production per ha (Muchena, 1987: 13). From an economic point of view this does not make sense. Although such grading is a good idea in biophysically oriented land evaluation, relative yields do not provide sufficient information to make conclusions about economic attractiveness of land use types. In this case, it would have been consistent to reformulate the suitability definitions.

2.3.4 Analysis at the (sub-)regional level, omitting the farm level as a unit of decision making

Although theoretically land evaluation recognises that land use types are part of farm systems, and therefore not independent (see above), in practice it only assesses the suitability of land use types for land units, without taking into account the farm as a unit of decision making. In a way it looks at land use at a (sub-)regional level, omitting the farm level. Many suitability assessments, although still relevant, are therefore less applicable for land use planning, and certainly for implementing a proposed land use change (Polman et al., 1982; Fresco et al., 1992; Erenstein & Schipper, 1993). Land evaluation could be become more applicable for such purposes, if land evaluation were also applied at the farm level (Fresco et al., 1992).

The problem of the level to which land evaluation is applied, is related to questions concerning the desired data and scale of analysis. The description of land use types in their proper context of farm systems and the regional economy, the establishment of requirements of land use types, and of the qualities of land units, require a huge amount of data, which most often can only be collected in a time consuming, labour intensive and costly process. For the practical applicability of land evaluation as an instrument for regional agricultural planning it would be important to design reliable, but less demanding methods. This is also
related to scale problems. For a technically accurate land evaluation a large scale is desirable. If possible it should be a scale at which individual farms can be distinguished. In that way, the land evaluation results can be linked to farming systems analysis. However, this is expensive and time consuming. For planning purposes smaller scales (depending on objectives and type of planning) are often sufficient or even better. Thus, the objectives of the planning exercise should dictate the scale of the land evaluation; Fresco et al. (1992: 20-21) provide some indications. Nevertheless, as these suggestions are rather general, there is no agreement yet on the preferred scale in each type of situation.
In this chapter, selected theories, methods and approaches relevant to land use will be discussed. The possible links with land use planning and land evaluation are also indicated.

The chapter starts with a discussion of land as an economic resource and sustainable development. Theories of land use are to be found in land and resource economics (Section 3.2), while methods comprise cost-benefit analysis (Section 3.3), farm management, production economics and household economics (Section 3.4). Other theories, approaches and problems related to land use decisions are discussed in Section 3.5. Important ideas concerning the use of land have been developed in the fields of regional economics and institutional economics. Regional economics includes the theory of comparative advantages (Section 3.5.1). Institutional aspects are discussed in so far as related theories are concerned with soil erosion and conservation (Section 3.5.2). Mention will also be made of the problems of 'micro-macro' linkages (Section 3.5.3) and linkages between the different sectors of an economy (Section 3.5.4). These problems will play a role in the formulation of the case study.

3.1 Land as an economic resource and sustainable development

Land

Land has a number of facets (Barlowe, 1986: 8-9). Land can be viewed as 1) space, 2) nature, 3) a factor of production, 4) a consumption good (amenity), 5) a situation (location), 6) property, and 7) capital investment. Other views are also possible, e.g. land as a sacred burial place of ancestors, or even as a deity itself. In the present study, land is mostly studied with regard to its natural qualities, its functioning as a natural resource, its location, and its characteristics as capital, both in the sense of natural capital, as well as of man-made capital, the more permanent - improvements to land.

In this respect, it is useful to provide a definition of the economic concept of land. This concept can be viewed as synonymous with the legal concept of real estate. It involves the natural and man-made resources that individuals, groups or communities control through the
possession of portions of the earth’s surface. (Barlowe, 1986: 8). This broad concept of land includes all the earth’s surface - water and ice as well as ground. In addition to building sites, farm soil, growing forests, mineral deposits, and water resources, it also involves access to such natural phenomena as sunlight, rain and wind, and changing temperatures and location with respect to markets and other areas. In short, land refers here to the resources it provides to mankind. Moreover, it includes all those man-made improvements that are attached to the surface of the earth and cannot be easily separated from it. To distinguish land as used here from a more general idea of land, it is often recommended that the term ‘land resources’ be used (Barlowe, 1986: 10). In this text, the word ‘land’ will mean land resources in the ‘Barlowian’ sense.

As is also stated in Fresco et al. (1992: 9), land is an example of a natural resource which, when properly managed, can be used repeatedly (‘renewable’), but of which the total quantity is limited. Land can be considered to be scarce if the supply of land is limited in relation to the demand for land by different users. Land is not uniform. It consists of unique units, each with specific characteristics and qualities arising from genesis, location and use. It is possible to grade land units according to their qualities. The scarcity of land can be interpreted in an absolute sense or relative sense, in other words, land can be just ‘out of stock’, or, by taking more and more land into use, it becomes more and more costly in terms of other resources to obtain the same amount of produce per unit of land.

Land can be used for different purposes, of which food production is just one example. As land can be used in different ways, it is important to select the way for which a particular piece of land is most suited and which best serves the interests of those involved, or at least to avoid unsuitable uses (Fresco et al., 1992: 9). Different land uses are often in competition with each other. Furthermore, the population of an area consists of different groups and individuals, each with their own interests. Consequently, there are bound to be conflicts over the use of land (Section 3.5.2).

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18 Renewable - being able to maintain or restore the ‘original’ state - must be considered in relation to certain qualities of land, like rainfall, location, and perhaps structure, if properly treated; other qualities, like fertility, are exhaustible and should be replenished either by nature or by man. Barbier, therefore, considers land a non-renewable resource (Barbier, 1989: 185), while considering soil or soil quality, a semi-renewable resource; see also Dixon et al. (1989: 75-76).
Agricultural production

To feed the (growing) world population adequately, as well as to generate growing incomes and increasing employment opportunities, it is necessary to increase the productivity of land. However, this should not be at the expense of land as a resource. Land should be conserved for future generations; land use should be sustainable. Land use planning and land evaluation have important roles to play in determining the best modes of sustainable land use (Fresco et al., 1992: 9).

It is estimated that the world population will grow from 5.3 billion in 1990 to 8.5 billion in 2025, and to 10.0 billion in 2050 (according to the medium fertility extension; UN, 1992a: 14). The yearly growth rate between 1990 and 2025 would be 1.4%, while between 2025 and 2050 this rate would be 0.7%. This medium variant assumes lower fertility than at present and consequently lower growth rates than at present (between 1985-90 the rate was 1.7%; UN, 1992b: 103). Extrapolating the projections for 1990 and 2025 to 2040, WRR (1994: 53) estimates that the population will be 9.4 billion (between 7.7 billion, low growth scenario, and 11.3 billion, high growth scenario). Will it be possible to feed such a population in the future, especially given the widespread poverty and hunger at the moment and current and future land degradation? The conclusion of the WRR study is positive. Depending on the scenario, it is shown that land resources on a world scale are sufficient to feed between 11 and 44 billion people if the best technical means available (implying no further land degradation) are used. So, in principle, from an agro-ecological point of view, potential food production can be sufficient. A recent comprehensive FAO study confirms this (Alexandratos, 1995). Earlier studies, for example Buringh et al. (1975) and Higgins et al. (1982), also indicated that the world could feed many more people than there are at present.

However, other studies, (Brown & Kane (1995) for example), point out constraints to increasing future food production, such as continuing land degradation (see below), loss of land to industrialisation and urbanisation, stagnation of fish catches, and limits to water availability. Furthermore, there are signs of diminishing investments in agricultural research. Their conclusions are largely based on an analysis of past trends and then extrapolating these into the future, such as in WRI (1992: 93-110) and WRI (1994: 107-128). Brown & Kane expect that the world

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19 See ‘principles’ of land evaluation (FAO, 1976), outlined in Section 2.2: suitability refers to use on a sustained basis.
Chapter 3

is close to its carrying capacity and that more emphasis should be put on trying to reduce population growth.

Moreover, whether the potential production level is realised depends to a large degree on social and economic factors, such as adequate investment in agriculture and appropriate policies. Besides, sufficient production does not mean that all people will be fed satisfactorily. The distribution of food (and other basic needs) between people is crucial. If every member of a society is to have access to sufficient food than (s)he must have rights to food, either by producing it or by obtaining it in another way (e.g. through buying, local distribution mechanisms or welfare). People must have sufficient entitlements (Sen, 1981 & 1990). In other words, it can be said that people must have sufficient purchasing power. Increasing purchasing power, through an increased demand for food, could induce a growing supply of food. Notwithstanding, given the realities of today, and the expectation that income distribution in most societies will not become more equal, there is little reason to expect that poverty and hunger are likely to disappear before 2040. This is substantiated in a paper of Pinstup-Anderson & Pandya-Lorch (1995) who claim, after reviewing population and food production trends, that, at least in 2010, there still will be a large number of ‘poor’ people (of whom many will be chronically under-nourished and underweight children), albeit relatively less than in 1990. Although there might be sufficient food in total, that does not mean that everybody will have sufficient to eat.

Land degradation

At present there is widespread concern about global sustainability issues (e.g. World Bank, 1992; Pearce & Warford, 1993). Climatic changes, environmental pollution and continuing population pressure on land coupled with the inability of many countries to meet the growing demands for agricultural products, present ‘mega-scale’ problems. These are no longer limited to the Third World, or portions of it, but affect all levels of the hierarchy of living systems, from the cell to the world economy. The need for some form of deliberate planning to make optimal use of the land resources at our disposal is evident. In this respect optimal use of land is efficient use in terms of partial and total factor productivities, together with sustainable use. In short, the aim is sustainable development.
Oldeman et al. (1991a) estimate that human-induced soil degradation has affected 1,964 million ha worldwide, or 15% of the total global land area of 13,013 million ha. This degradation has probably occurred since the end of the Second World War (Oldeman, 1992: 23). Deducting non-used waste land and stable terrain under natural conditions from the total area (4,278 million ha), the percentage of degraded land increases to 23%. About two billion hectares degraded over a period of 50 years is equivalent to 40 million hectares per year (estimated as $1,964 \times 10^6 / 50$). This has rather alarming implications for the long run.

Land degradation can be specified according to degree, type and cause. Four grades of degradation are distinguished. Of the 1,965 million ha degraded land, 38% is lightly degraded, 46% moderately, 15% strongly and (less than) 1% extremely degraded (Oldeman et al. (1991b). Table 3.1 has been compiled by combining the type of degradation with its human-induced cause. As can be seen from this table, water erosion is the most important type of land degradation.

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20 See Yadav & Scherr (1995) for a recent comparison of studies of land degradation. The two Oldeman et al. studies (1991a & 1991b) appear to be the most authoritative at the global level.

21 Although one year earlier, Oldeman et al. (1991b: 33) state that "It is not possible to indicate the rate of human-induced soil degradation."

22 More accurately said, by deducting 8,735 million ha of 'land-in-use' (the sum of agricultural land use (1,475 million ha), permanent pasture (3,212 million ha) and forest and woodland (4,048 million ha) (FAO, 1990)) from the total land area under consideration (13,013 million ha), a figure of 4,278 million ha is obtained, the total amount of stable terrain under natural conditions and waste land (Oldeman, 1992: 22-23). Stable terrain with a permanent agricultural land use and terrain stabilized by human intervention are, of course, included in one of the three categories of 'land-in-use'.

23 Other estimates are perhaps less alarming: for example, between 5-7 million ha annually (land loss, Dudal, 1982; FAO/UNEP, 1983), or 6 million ha annually (desertification, UNEP, 1984); both cited in Yadav & Scherr (1995: 85). Yadav & Scherr also refer to Oldeman et al. (1990) as reporting 5-6 million ha of land loss per year, but this can not be confirmed. Oldeman et al. (1991b: 2) in turn refer to WCED (1987) as indicating that "The loss of agricultural land through erosion is estimated at 6 to 7 million ha per year with an additional loss of 1.5 million ha annually as a result of waterlogging, salinization and alkalinization."

24 It is also of interest that the distribution of degraded areas by type and cause is not evenly spread over the world. For details see Oldeman et al. (1991b), and Oldeman (1992).
followed by wind erosion. Together they form 86% of the more serious stages of land degradation. Deforestation, overgrazing and agricultural activities are the most important human-induced causes of land degradation, each accounting for roughly one-third of the total. However, deforestation causes most water erosion, while wind erosion is mostly a result of overgrazing.

Table 3.1  Type and human-induced cause of soil degradation (percentages)

<table>
<thead>
<tr>
<th>Human-induced cause</th>
<th>Type of soil degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>water</td>
</tr>
<tr>
<td>deforestation</td>
<td>24</td>
</tr>
<tr>
<td>overexploitation</td>
<td>2</td>
</tr>
<tr>
<td>overgrazing</td>
<td>16</td>
</tr>
<tr>
<td>agricultural activities</td>
<td>14</td>
</tr>
<tr>
<td>(bio)industrial activities</td>
<td>1</td>
</tr>
<tr>
<td>total</td>
<td>56</td>
</tr>
</tbody>
</table>

Based on Oldeman (1992: 32)

In view of the continued population growth, it could be important to restore the productive capacity of the degraded land. As we have seen above, this might be easy for lightly degraded land\textsuperscript{25}, but it would be progressively more difficult and expensive for the more serious stages of land degradation. In view of the definition of moderately degraded land\textsuperscript{26}, it might still be economically attractive to rehabilitate this type of

\textsuperscript{25} Lightly degraded land: the terrain has only a somewhat reduced agricultural suitability, but is suitable for local farming systems; restoration to full productivity is possible by modifications to management; original biotic functions are largely intact; Oldeman (1992: 23).

\textsuperscript{26} Moderately degraded land: the terrain has a greatly reduced productivity, but is still suitable for use in local farming systems; major improvements are required to restore to full productivity, which are beyond the means of local farmers in developing countries; original biotic functions are partially destroyed (Oldeman, 1992: 23-24).
Economic theories of land use

land. However, it is not likely that this applies to strongly degraded land\textsuperscript{27}, let alone to extremely degraded land\textsuperscript{28}. Of course, next to rehabilitation, the most prudent action is to avoid or reduce as much as possible future degradation of presently non-degraded land, and to avoid that land already degraded to a certain degree becoming more seriously degraded.

**Sustainable development**

Sustainable development is a form of development which leaves the next generation with a similar, or better, resource endowment than that which the present generation inherited (Pearce, 1989)\textsuperscript{29}. More precisely, it can be defined as "A development strategy that manages all assets, natural resources, and human resources, as well as financial and physical assets, for increasing long-term wealth and well-being. Sustainable development, as a goal rejects policies and practices that support current living standards by depleting the productive base, including natural resources, and that leaves future generations with poorer prospects and greater risks than our own." (Repetto, 1986)\textsuperscript{30}. According to Pearce *et al.* (1990: 4), a key necessary condition is the 'constancy of the natural capital stock'. They continue: "More strictly, the requirement is for non-negative

\textsuperscript{27} Strongly degraded land: the terrain has virtually lost its productive capacity and is not suitable for use in local farming systems; major investments and/or engineering works are required to rehabilitate the terrain, which are often beyond the means of national governments in developing countries; original biotic functions are largely destroyed (Oldeman, 1992: 24).

\textsuperscript{28} Extremely degraded land: the terrain is unreclaimable and beyond restoration; it has become human-induced waste land; original biotic functions are fully destroyed (Oldeman, 1992: 24).

\textsuperscript{29} The WCED (1987: 43) provides a similar definition, but places more emphasis on the needs of different generations: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." They continue: "It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and

- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

\textsuperscript{30} Compare to WCED (1987: 46): "In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technology development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."
change in the stock of natural resources and environmental quality. In basic terms, the environment should not be degraded further but improvements would be welcome." However, no definition is provided of the natural capital stock, nor its components, the different natural resources. Also, formulated in this way, this condition is too general and therefore not very helpful; compare this condition also with the position taken by Van Pelt et al. (1990), who argue that substitution between natural capital and man-made capital, under certain provisos, should be possible. Scott (1995) rejects the notion of natural capital stock as unclear and not necessary. What counts are stocks of particular (natural) assets, which should or should not be maintained in view of (sustainable) consumption of those assets. Dasgupta & Mäler (1995: 2393-2394) consider the constancy of natural capital stock as a 'category' mistake, "the mistake being to identify the determinants of well-being (e.g. the means of production of the means of production of well-being) with the constituents of well-being (e.g. health, welfare, and freedoms)." Furthermore, they see it as an impossible goal. "History, introspection, and experience with analytical models since the early 1960s tell us that reasonable development paths would involve patterns of resource substitution over time." (Dasgupta & Mäler, 1995: 2394). Nevertheless, the 'philosophy' of a 'constancy of the natural capital stock' is helpful to remind us that economic development should be or is constrained by the limits of the natural environment.

Pearce & Turner (1990: 24) provide a 'working' definition of sustainable development. "It involves maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time." Economic development is seen by Pearce and Turner as including not just increases in real per capita income but also other elements of social welfare. Development will necessarily

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31 The idea that economic development is limited by a certain natural capital stock is similar to the concept of an 'environmental utilisation space' (Opschoor, 1987). As defined in Opschoor (1992: 28), "One can think of nature as presenting to society an environmental utilization possibilities frontier defined as the locus of sustainable patterns of economic development in terms of their claims on the biosphere. The biosphere only allows a limited 'amount' of effective metabolism on the environment-economy interface, even if this limit can be extended through scientific and technological advance. Metabolism here is the sum of resources (matter and energy) mobilized by society and the wastes and pollution released into the environment. Sustainability implies that: 1) this metabolism does not impair the present and future functioning of resource regeneration systems, waste absorption systems and the systems supporting flows of other environmental services and goods, and 2) use of nonrenewable resources is compensated for by at least equivalent increases in supplies of renewable or reproducible substitutes."
involve structural change within the economy and in society. According to Pearce & Turner (1990: 24) maintaining the services and quality of the stock of resources over time implies, as far as is practicable, acceptance of the following rules:

a) utilise renewable resources at rates less than or equal to the natural rate at which they regenerate (to which they add (1990: 44): keep waste flows to the environment at or below the assimilative capacity of the environment);

b) optimise the efficiency with which non-renewable resources are used, subject to substitutability between resources and technical progress.

Because of rule a) the stock of renewable resources and the assimilative capacity will not fall. Therefore, the idea of the 'constancy of the natural capital stock' is implicit. However, there are several caveats. First, by definition, this cannot be true for non-renewable resources, see therefore rule b). Second, the stocks referred to are not static. They can change through natural processes (e.g. assimilation) or through management by man. Third, rule a) places emphasis on the role of natural resources and the environment, but are they that essential, and can they not be substituted by man-made capital?

Rule b) emphasises the possibility of substitution between resources and of technical progress towards a more efficient use of non-renewable resources. Substitution can be between non-renewable resources (e.g. aluminum window frames) and renewable resources (e.g. wooden window frames), or between non-renewable resources (e.g. copper telephone lines) and man-made capital resources (e.g. glass fibre lines). Furthermore, different renewable resources can be substituted for each other (e.g. meadows for forests). Technical progress can result in using less natural resources now than before (e.g. cars use fuel more efficiently). Most of the changes in resource use are a mixture of substitution and increased efficiency. Also, most man-made capital resources are made from renewable or non-renewable resources or from a mixture of both. Important questions are therefore to what degree substitution is possible and to what extent mankind can rely on technical progress. Related questions in this respect centre around uncertainty and irreversibility.

A general definition of sustainable development has to be worked out and made specific to the planning of sustainable land use in specific areas, for example as is being done for the case study in Section 5.2.2; see also Jansen et al. (1995). Sustainability differs according to the level of analysis (Fresco & Kroonenberg, 1992; Holling, 1995). For example, it is quite different whether one asks how much forest has to be conserved on a national scale, or whether a particular forest in a
particular area should be conserved. Nijkamp et al. (1991) state that \textit{regional sustainable development} and \textit{sustainable resource use} should always be compatible with global sustainability. They employ the concept of \textit{critical success factors} as necessary conditions for balanced regional development which could be guided by policy interventions. The critical success factors can be compared with the ‘sustainability parameters’ to measure the quality and quantity of natural resources as proposed in Section 5.2.2.

Sustainability also differs when applied to a region as a whole (‘an area relatively unsuited for maize cultivation’) from applying it to a farm in that region (‘a smallholder cultivating maize for subsistence and sale without adequate alternatives’). It is also not clear how different natural resources (e.g. land, vegetation, minerals) can be aggregated into a meaningful concept of natural capital stock. Apart from inadequate knowledge about the quantity and quality of the different resources, there is the question of the valuation of the different resources, which is necessary for aggregation. Furthermore, it is not clear whether different natural resources can be substituted for each other (e.g. pastures for forests) or for man-made capital (e.g. water reservoirs for irrigation purposes in areas currently under rainfed agriculture), and to what extent this can be done without jeopardising long-term sustainability (van Pelt et al., 1990).

Although the sustainability issue provides a separate dimension to the economic theories of the use of land, it does not alter the land use planning problem in principle. It adds the objective that the use of land should be such that land, as a resource, is conserved for the future, to the objective of economic efficiency and to questions about the distribution of benefits and costs over different groups in society. In other words, it puts extra constraints on the use of land.

3.2 Resource economics

Resource economics, as opposed to environmental economics, is not a new area of economics. The use of land, and especially the limitations of land in relation to population growth, was one of the great concerns of ‘classical’ economists such as Malthus and Ricardo\footnote{Adam Smith was not concerned with the economic dependency on land and its limits, he only saw that distributional and social responses to the relative scarcity of agricultural output would eventually produce a stationary state (Barbier, 1989: 5).}32. They explored the
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social, economic and natural conditions determining economic growth. In contrast, contemporary ‘neoclassical’ or ‘conventional’ approaches to resource economics, are more concerned with the allocative efficiency of the market system and how this affects the exploitation of natural resources. In addition to the contributions of classical and neoclassical economists, the relevance of the theories of agricultural development of Boserup (1965) and of Hayami & Ruttan (1985) is also discussed. Finally, attention is given to a recent approach by Barbier (1989) to the issue of sustainability, incorporating linkages between economy and ecology, and the laws of thermodynamics.

However, before presenting the above theories, it is useful to discuss land economics first. As a specialisation of agricultural economics, land economics is closely related to resource economics.

3.2.1 Land economics

According to Barlowe (1986: 3) "Land economics deals with the economic relationships people have with others respecting land." It deals with the economic use of the surface resources of the earth, and the physical, biological, technical, economic and institutional factors that condition and control the use of these resources. Land economics originated around the beginning of the 20th century in the USA, but went out of fashion after the 1950s.

Land economics is concerned with the allocation and use of scarce resources, the chief focus being on one particular type of resource: land. However, land economics does not concentrate exclusively on land, if only because land can only be used together with other factors, such as labour and capital. In this way, it could be compared to other branches in economics, like, for example, labour economics (Barlowe, 1986: 4).

Although land economics is interested in the application of economic concepts, it is at the same time oriented towards finding solutions to empirical problems. This has led to the recognition that other aspects concerning the use of land need to be taken into account. Land economics therefore tends to use ideas from other disciplines, e.g. psychology, political science, sociology, business management, geography, soil science, agronomy, irrigation science, forestry, in order to be able to provide relevant 'solutions' to land allocation problems (Barlowe, 1986: 4).

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33 Reviews of the main ideas of land economics can be found in, among others, Ely & Wehrwein (1948), Salter (1948) and Ciriacy-Wantrup (1952).
Barlowe (1986: 4-7) clarifies this approach by presenting a threefold framework with (1) physical and biological factors, (2) technical and economic considerations, and (3) institutional arrangements. He compares these factors with the three primary colours (red, blue and green) necessary to produce full colour television.

Land economics is also concerned with the analysis of conservation issues (see Castle et al., 1981: 420-422). An important contribution comes from Ciriacy-Wantrup, who views conservation as concerned with the inter-temporal distribution of resource use. "More specifically, 'conservation' and its logical corollary, but economic opposite, 'depletion' are defined in terms of changes in the inter-temporal distribution of use. In conservation, the redistribution of use is in the direction of the future; in depletion, in the direction of the present." (Ciriacy-Wantrup, 1952: 51). Such a definition provides a standard by which conservation can be judged and made amenable to economic analysis (Castle et al., 1981: 421).

3.2.2 Classical economics views

As mentioned before, land is an example of a resource for agricultural production which can be used repeatedly ('renewable') but of which the total quantity is limited in view of the demand for land ('scarce'). It is important to distinguish between land of different quality. Land of a good quality has a higher yield of (or lower cost of cultivating) a certain crop (land use type) than land of a lesser quality, at the same input level (at the same yield level). According to Ricardo (1821), first the better quality land will be brought into use and subsequently land of decreasing quality, as needs increase (e.g. due to population growth). This is illustrated in Figure 3.1.

![Figure 3.1](image)

Figure 3.1 Possible relations between the value of production and the costs per ha, and the quantity of land
The value of the production diminishes and finally dips below the costs of production each time land of lesser quality is brought into use (version a) of Figure 3.1). In version b) of the same Figure, more costs (e.g. for weeding or fertiliser) have to be made each time to obtain the same production. This is known as relative scarcity.

The idea that better quality land (or land with lower cultivation costs) will be brought into use first and subsequently land of decreasing quality, can be disputed. Much depends on the time frame (years, decades, centuries, millennia) taken, on considerations of distance, the level of analysis (farm, (sub-)regional, national, global), and on who has used the land first and subsequently. In this respect, an early agricultural development planner (Mosher, 1969: 59-70) recommended giving priority to land with an ‘Immediate Growth Potential’ over land with ‘Future Growth Potential’ and ‘Low Growth Potential’. He argued that in that way the highest returns on investments would be obtained. The growth potential concept of Mosher can be compared to Barlowe’s land use capacity (Section 2.1).

According to Ricardo, in the long run, no more land can be taken into use, and, consequently, population cannot exceed a certain maximum. Malthus (1798) was even more radical than Ricardo by positing only one quality of finite land, in other words, assuming an absolute scarcity of land. For an interesting exposé of these classical ‘scarcity and growth’, and other theories, as well as testing whether resources on a global scale are indeed becoming scarcer, reference is made to the seminal work of Barnett & Morse (1963).

### 3.2.3 Scarcity of land mitigated

According to Ricardo the tendency of decreasing production could only be broken through technical progress or innovations which increase production or diminish costs. Both Ricardo and Malthus were pessimistic about the possibilities for technical progress in agriculture in the long run. Another possibility is substitution on the output side of the production process, e.g. millet by cassava (Fresco, 1986: 133 & 143-34).

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34 In other words, one could say that the quality of land must be related to the objectives and means of the people using land. Compare this with Marshall (1920: 133-137). Therefore, the Ricardian concept of quality of land involves both accessibility and resource quality, the two components of Barlowe’s land use capacity (Section 2.1).
The substitution of, for example, millet by cassava also occurs because of shorter fallow periods causing lower soil fertility; cassava can still use the remaining nutrients.

Defined in a similar way as the R-factor of Ruthenberg (1980: 15). The R-factor is calculated as \( R = \frac{U}{U + N} \), in which \( U \) is the number of years a certain tract of land is used and \( N \) the number of years it is not used. If land is used more than once within a year ("multiple cropping") \( R \) is multiplied by a factor indicating such a use. \( R \) is usually expressed as a percentage.

Boserup (1965) sees the emergence of absolute and relative scarcity of land really happening. However, in her view this can be overcome. She considers population growth as the driving force behind the emergence of a more intensive agriculture. Thus, Boserup describes a positive relation between population density and land use intensity. She defines the degree of intensity\(^{36}\) of a type of agriculture as the time period that a certain tract of land is used for this type of agriculture in relation to the period that it is not used. She advances the hypothesis that the following five types of agriculture are historical stages of the agricultural development in tropical countries: 1) swidden agriculture, 2) bush-fallow agriculture, 3) short-fallow agriculture, 4) annual cropping, and 5) multiple cropping. This sequence of stages means a change in land use, or to speak in terms of land evaluation, a change in ‘major kind of land use’ (FAO, 1976 & 1983). This concerns a kind of substitution on the output side of the production process, since other products are often involved. In addition to ‘substitution’, the step from one type of agriculture to another implies a change in technology, or innovations. A further aspect is the increased labour use per hectare progressing from type 1 to type 5. This increased labour effort may result in decreasing labour productivity (units of output per unit of labour-time). Boserup observes an empirical decrease in labour productivity, but does not see this as a theoretical necessity. This depends on the change in technology (production function) (Robinson & Schutjer, 1984).

The major hypothesis of Boserup can be summarised as follows: it is not the biophysical environment that determines the agricultural system, rather it is the need to increase food production, caused by, for example,

\(^{35}\) The substitution of, for example, millet by cassava also occurs because of shorter fallow periods causing lower soil fertility; cassava can still use the remaining nutrients.

\(^{36}\) Defined in a similar way as the R-factor of Ruthenberg (1980: 15). The R-factor is calculated as \( R = \frac{U}{U + N} \), in which \( U \) is the number of years a certain tract of land is used and \( N \) the number of years it is not used. If land is used more than once within a year ("multiple cropping") \( R \) is multiplied by a factor indicating such a use. \( R \) is usually expressed as a percentage.
population growth, that determines the agricultural system, within certain ecological boundary limits. This is an optimistic point of view, because people would be able to adjust to changing circumstances and still feed themselves.

A number of objections have been made to Boserup’s theory. In part these are similar objections to theories of ‘stages’ of development in general, like Rostow’s theory of development (1961). One question is whether these stages are only a possibility or a necessity. Another question is how to identify the boundaries between stages; at what moment is there a transition from one stage to the next? The following objections are more specific to Boserup’s theory:

a) is a regression from type 5 to type 1 possible if population decreases?

b) ecology is a ‘boundary condition’: not all types are possible in all tropical environments;

c) adaptation to changed circumstances and transition of one type into another does not always occur: e.g. ‘aborted’ agrarian societies;

d) the ‘average’ farming system in a society is not the same as the individual farm system, or, in Boserupian terms, several agricultural types might exist at the same place and time; and

e) what is the influence of autonomous factors, such as natural disasters, or other exogenous influences, like colonialism or (foreign) trade?

Boserup’s theory presupposes ‘closed’ societies.

The evolution of agricultural systems in Africa is illustrated in a study by Pingali et al. (1987). One purpose of this study is to test the hypothesis of Boserup (and similar ideas developed by Ruthenberg, 1980). Based on a cross-section of 52 locations in different countries in Sub-Saharan Africa, a marked correlation is found between population density and the agricultural system. However, the ‘ecology’ of an area does pose certain limits on the development of agricultural systems. Other factors, for example the possibilities for marketing certain crops, also have a strong influence on this development.

Population density can not only stimulate agricultural development, it can also contribute to environmental recovery. *More people, less erosion* is the catchy main title of a study of the improvement of the environment in Machakos District in Kenya (Tiffen et al., 1994). Comparing the situation with respect to land degradation in 1930 with that of 1990, based on numerous reports and photographs of the same sites, they concluded that land resources have improved, in spite of a nearly six-fold population increase. More land has been brought under cultivation, while the agricultural technology has changed over the years. The change in technology has brought about an increasing capital intensity {capital per ha; in the form of capital invested in improving land (e.g. terraces)}
and/or capital goods}. The amount of labour use per hectare of cropped land has decreased. They consider the increase of population density to be the main force behind the environmental recovery. A larger population density stimulates the demand for food, provides more hands and brains, and leads to cheaper interaction costs per km$^2$. In conjunction with improved market possibilities and remittances from (temporary) labour migration, both providing sources for investments, and reasonable government policies, it made investment for land improvement worthwhile (Tiffen & Mortimore, 1994).

With respect to market opportunities, the ‘staple’ (Innes, 1927) and the ‘vent-for-surplus’ (Myint, 1958) theories of agricultural development are of interest (Hayami & Ruttan, 1985: 42-45). Rijk (1989: 11) discusses both theories in the context of agricultural mechanisation in Thailand. The ‘staple’ theory refers to the availability of abundant land and other natural resources which makes it possible to produce a large quantity of a basic commodity, which forms the basis for agricultural development. The ‘vent-for-surplus’ theory is similar, but emphasises the opening-up of new markets, which creates a new opportunity for agricultural development. However, in both theories, the abundance of land and other natural resources are the basic ingredients (as well as markets), rather than scarcity of land (supply of food) in relation to population (demand for food), causing more intensive use of land.

Boserup’s theory resembles the more general theory of ‘induced innovation’ of Hayami & Ruttan (1985). This theory states that innovations are ‘created because of’, or are ‘deducted from’, the relative scarcity and the relative prices of factors of production. This is illustrated by comparing technical progress in agriculture in Japan with that in the USA. Technical progress has been different in both countries, because in the USA labour was the most scarce factor, while land was the most scarce factor in Japan. As technical progress is caused by the relative scarcity of factors and their prices, it is considered an endogenous variable, that is to say within the economic system. This is opposite to the view that technical progress is autonomous and should be considered as exogenous to the economic system.

The conclusion that relative prices of factors of production determine to a large extent the choice of technology and influence the path of technological development, also presents an explanation for the observation that innovations are often adopted more quickly and to a greater extent by larger farmers than by smaller farmers, even when

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specific innovations are in principle scale-neutral with regard to land, such as high-yielding varieties. It can be argued that larger farmers pay different prices for capital and labour than smaller ones. Larger farmers can often obtain credit at cheaper rates than smaller farmers. On the other hand larger farmers have to hire labour against market wage rates, while smaller farmers can use their own, cheaper, family labour. Fertiliser may also be cheaper for larger farmers than for smaller ones because they need more and can obtain price reductions. For recent reviews of the adoption of 'green revolution' technology and the different consequences for different groups in developing countries, see Lipton & Longhurst (1989), Alauddin & Tisdell (1991) and Hazell & Ramasamy (1991).

The theory of Hayami and Ruttan treats technical progress as endogenous (as does Boserup's theory), in contrast to Ricardo and Malthus, who see technical progress as exogenous to the economic process. Because Ricardo and Malthus are pessimistic about the technical progress in the long run, they are also pessimistic about possibilities for economic development. Boserup, and Hayami & Ruttan are more optimistic since they believe that changes in circumstances force new technological developments, which cope with problems and constraints, and make use of possibilities and opportunities. Lipton (1990) argues that the theories of Malthus, Boserup and Hayami & Ruttan, "often seen as opposed in logic and policy implication, are in fact parts of a single approach." It depends mostly on institutions (e.g. concerning distribution ('entitlements') and technical change) whether "better outcomes normally mean aggravation later (more food today means more people with less food per capita tomorrow) or whether "better outcomes remediably mean aggravation later" (more people, more food, and possibly again more people, depending on the adequacy of the institutional response whether people are finally worse-off). For a similar comparison between Malthus and Boserup, with excursions into Marx, Geertz and Von Thünen, see Netting (1990: 261-294).

The theories mentioned above, interesting as they are for an analysis of the past, do not necessarily solve problems in concrete situations when a plan must be made, a decision taken or just something must be done, in the context of land use planning. However, they certainly can steer longer-term decisions with regard to the kind of agricultural research that is needed, and with regard to government policies for prices (and exchange rates).
3.2.4 Contemporary theories

Contemporary approaches (Barbier, 1989: 4) to the economy of natural resources concentrate on:
" - the role of price as a measure of 'relative' (exchange) scarcity;
 - the role of natural resource inadequacy as an 'absolute' constraint on growth; and
 - the role of technical progress in alleviating any scarcity-induced constraints on growths."

Following the analysis of Hotelling (1931), a large body of literature is devoted to the question of the 'optimal rates of depletion' of natural resources. Examples are Dasgupta & Heal (1974) and Solow (1974). For a clear exposition and overview, see Howe (1979). A recent survey can be found in Barbier (1989). This subject will be outlined in Section 3.2.4.1. Dasgupta & Mäler (1995) emphasise the particular situation in developing countries with regard to their environmental-resource base in relation to existing poverty and institutions.

Another part of the literature of environmental economics is more concerned with pollution and waste generation. Pollution (including waste) is regarded as an external cost for producers and consumers alike (Baumol & Oates, 1988). A mixture of proper taxation and control measures could internalise the costs and therefore reduce pollution. The problems surrounding pollution and waste are not discussed here, as these are at present less relevant to land use in developing countries.

A subject of interest is the question of the influence of property rights on the exploitation of natural resources. A useful distinction can be made between private property, common property and open access resources (Magrath, 1989), and will be further discussed in Section 3.2.4.2.

3.2.4.1 Optimal rates of depletion

A common classification of natural resources is in two categories: non-renewable and renewable\textsuperscript{38}.

\textsuperscript{38} A frequently used terminology is exhaustible versus renewable resources. However, a number of writers, e.g. Pezzey (1990: 2) prefer the terms non-renewable versus renewable to avoid confusion about the exhaustibility of renewable resources. When wrongly managed, some renewable resources clearly can be exhausted, for example, forests. Without natural regeneration or replanting by man and subsequent care they are not renewed. Pezzey therefore makes the following subdivision, including some examples:

(continued...)
Non-renewable resources

Under simplified assumptions \( \{ \) production \( Q \) in a certain year \( t \) as a function of capital (and labour) stock \( K \) and natural resource commodity \( R \); production \( Q \) which can be used for consumption \( C \) and investment \( I \) in the capital stock \( K \); and consumption \( C \) that is to be maximised over time, given the initial availability \( S_0 \) of the resource stock and a discount rate \( r \) \} the optimal rate of depletion of a natural resource - with regard to consumption over time - can be derived (Barbier, 1989, following Dasgupta & Heal, 1974). The Hotelling 'rule' follows from the same assumptions that - under optimal exhaustion - the price of the natural resource should increase at the same rate as the discount rate (e.g. Heijman, 1990). Otherwise, it would pay to over-exploit the resource and to invest the proceeds at the discount rate, if the price rise is lower than the discount rate. Conversely it would pay to under-exploit the resource and to sell the resource in the future, if the price rise is higher than the discount rate.

Although the depletion rate is optimal with regard to consumption over time, the resource will nevertheless be exhausted. If the resource is essential - that is to say the resource cannot, or only in part, be substituted by capital - the consequence is detrimental, as consumption would eventually decline to zero. Only technical progress - in the sense that each year less of the natural resource per unit of production is required - could avoid this ultimate consequence (Dasgupta & Heal, 1974).

Although somewhat less simple models have been introduced, incorporating technical progress (Kamien & Schwartz, 1978), uncertainty (Dasgupta & Heal, 1979; Dasgupta & Stiglitz, 1981), different market forms (Heijman, 1990), different production functions (Solow, 1974), as well more than one final product and more than one type of resource (Pezzey, 1989), these models are still far too simple to be of relevance for the present problem of how 'best' to use land in a regional setting.

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38(...continued)

1. non-renewable materials (metals) 3. renewable materials (plants)
2. non-renewable energy (fossil fuels) 4. renewable energy (solar).

In the present paper the term non-renewable is preferred to exhaustible.

Barbier considers an 'in-between' category: semi-renewable; and mentions examples as soils (Barbier, 1989: 95), or soil quality, the assimilative capacity of the environment and ecological life-support systems (Barbier, 1989: 185), and the ozone layer. He is not very clear about this, but compare the remark in note 19.
However, they are useful in providing general guidelines for the use of non-renewable resources.

**Renewable resources**

With similar simple models as in the case of non-renewable resources, the optimal use of a renewable resource - which might imply exhaustion - can be established. See, for example, Howe (1979: 256-275). A classic paper is Smith (1974). An interesting new approach, in particular with regard to the criterion for evaluating alternative growth paths, depending on the sum of utilities over time and the long-run behaviour of utility values ('Chichilnisky criterion'), can be found in Beltratti et al. (1994).

The difference with non-renewable resources lies in the fact that the stock of a renewable resource can grow, either by natural regeneration or through man's actions (Barbier, 1989). In simple formulas:

- **renewable**: \( \frac{dS}{dt} = f(S,K_1) - R; \quad R = g(S,K_3) \);
- **non-renewable**: \( \frac{dS}{dt} = -R; \quad R = h(S,K_3) \);

in which the symbols have the same meaning as above, with the subscripts under K indicating different types of capital. The term \( f(S,K_1) \) in the first formula indicates that the stock of the renewable resource can grow as a function of the resource stock itself ('regeneration') or through the action of man via the allocation of capital (and labour) to the natural resource ('establishment and care of seedlings'). "The optimal rate of exploitation of a renewable natural resource equates the marginal value, or price, of a harvested unit net of its value as living biological capital (i.e., its unharvested value) with the marginal harvesting costs." (Barbier, 1989: 67). In a 'free' market, the unharvested value could be established through competitive bidding. In the case of an open access resource (e.g. ocean fishery) this value is zero, which might lead to over-exploitation (Barbier, 1989: 66-70). As stated before, these types of models provide general guidelines only.

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39 S: stock of resource; R: resource commodity; K_1: capital for regeneration of renewable resource; K_2: capital for renewable resource extraction; K_3: capital for non-renewable resource extraction.

40 Other relevant texts on the exploitation of (renewable) natural resources are: Conrad & Clark (1987), Neher (1990) and Pearce & Turner (1990).
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3.2.4.2 Natural resources and property rights

An important consideration in economic theory is whether the use of a natural resource is influenced by property rights. It is. Economic theory argues that the absence of (fully articulated and enforced) property rights will lead to free riding and to inefficient resource allocation resulting in social losses (Magrath, 1989: 1). Recent experiences with, for example, pasture degradation in pastoral societies in Africa where individual property rights with regard to grazing land do not exist, appear to support the hypothesis about the relation between the absence of property rights and free riding. The resulting pasture (and land) degradation is often referred to as the ‘tragedy of the commons’ (Hardin, 1968). With communal land ownership each individual can maximise his ‘share’ of a pasture by increasing his own livestock holding as far as he can, which leads to collective overstocking, in turn resulting in degradation of the pasture, something which, conversely, the individual cannot avoid by unilaterally limiting his herd. The overstocking and consequent destruction of the environment is caused by ‘private cattle on common land’. This theory hinges on the assumption of private ‘profit’ maximisation and the absence of (enforced) rules of the community with regard to the management of the resource. In fact this is only true for so-called ‘open access’ resources, e.g. ocean fishery, but not in the case of ‘common property’ resources, e.g. communal woodlots. In the case of common property, the property of a resource is shared by the members of a community. The community can set rules, and normally does, for a proper exploitation. In the case of open access resources, the resource is no one’s property, and there is no community which can set rules for exploitation.

It is useful to make the following two-way classification of natural resources on the basis of the ‘cost of exclusion’ and the ‘cost of coordination’ (Magrath, 1989: 4), see Figure 3.2.
In the case of open access resources the cost of exclusion of other users by individuals as well as the cost of coordination by the community (society) are (too) high, and the situation become a 'free-for-all' (ocean fishery, disintegrating pastoral societies). In the case of common property resources it is (too) costly for individuals to exclude others, but the community is able to enforce rules regarding the use of the resource (stable pastoral societies). In the case of private property, individuals are able to exclude others from using 'their' (part of) natural resource (land units), but it would be (too) costly for society to coordinate the use of land (e.g. arable farming).

Theories about the use of common property resources are important for land use planning, as large parts of the land resources are actually outside (private) farms: water sources, rivers, woodlots, windbreaks, grazing lands, (primary) forest reserves, etc. For a simple explanation of economic theories of common property in the context of pastoralists, including possible measures (taxes, quota, privatisation of property rights), see Sommerville & Kerr (1988); Bromley (1992) is more elaborate. Livingstone (1986) questions the assumptions about individual profit motivation and the lack of collective rules. He also shows that individual and collective behaviour of pastoralists is quite rational in view of the variability of natural conditions and the risks involved. Pastoral development under uncertain circumstances is treated from various points of view in Scoones (1994). Magrath (1989) gives an extensive treatment of the problems with regard to non-exclusive resources, including the 'standard open access' problem, the costs of open access regimes, alternative approaches to non-exclusive resources, tools for the management of those resources, and what he calls the 'future' of the commons.
3.2.5 An extension to economy-ecology links

The theories of natural resource exploitation outlined in the former sections can be extended by studying the two-way relationships between the economy and its environment, the latter roughly equivalent to the ecosystem, in part based on the laws of thermodynamics. The environment has three functions for the economy (Barbier, 1989: 95-96):
1. it provides resources that become the material and energy inputs into the economic process;
2. it assimilates the emitted wastes of the economic process; and
3. it provides a flow of 'natural' or 'environmental' services to individuals and to production systems.

Before turning to the concept ecosystem, it is useful to consider the concept of a system. A system involves an arrangement of components (or subsystems) which processes inputs into outputs. Systems display special properties that emerge from the interaction of components. Knowledge of the parts only, therefore, is not sufficient to adequately predict the behaviour of the system as a whole. In all systems five elements are distinguished: components, interactions between components, boundaries, inputs and outputs. The structure of a system is defined by the quantitative and qualitative characteristics of the components and the interactions between them. The way in which inputs are processed into outputs determines the function of a system. Within the boundaries all relevant interactions and feedbacks are included, so that all those components that are capable of reacting as a whole to external stimuli form a system (Fresco et al., 1992: 192).

The above concept of system can be applied to the environment: an ecosystem, sharing a number of characteristics. In the context of

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41 According to Fresco (1986: 41), following Odum (1983), an "ecosystem comprises one or several biological communities, composed of various populations, that interact with the physical environment. Each population consists of individual organisms that in turn consist of organs that consist of cells. Consequently, ecosystems are based on a hierarchical relationship: each subsystem is at the same time a system in itself with its own subsystems as well as a part of a larger system (also called the supra-system). The hierarchy involves successive energy quality transformations: at each step much of the energy is used in the transformation and only a small amount is transformed into higher quality."

Higher quality refers to the sense of having a state of lower entropy, see main text below.

42 Pianka (1983: 4-5) describes these characteristics as follows: "There is a natural sequence to the subject matter of ecology, proceeding from the inorganic to the organic (continued...)"
the present study, it makes sense to distinguish natural ecosystems from, human-based, agro-ecosystems. Natural ecosystems have three basic properties: productivity (number/biomass of individual species), stability (constancy) and resilience (Conway, 1987: 100; as defined in Holling, 1973). According to Conway (1987: 100), agro-ecosystems, which can be interpreted as natural ecosystems modified by human beings for the purpose of agricultural production, have the following four properties: productivity, stability, sustainability (resilience)\(^43\) and equitability. These properties relate to the social value of the system. Attempts to maximise the social value influence the properties and consequently the agro-ecosystem (Barbier, 1989: 49-50). Conway does not discuss why these properties are singled out and if these properties are the only relevant ones. Especially with regard to equitability, it is questionable whether this is an inherent property of a specific agro-ecosystem or a more general feature of the social organisation of the human population in question.

Conway (1987: 100-103) defines the four properties of agro-ecosystems as follows:

\(^{42}\)(...continued)

world. ... The climate, soils, bacteria, fungi, plants, and animals at any particular place together constitute an ecosystem. Thus each ecosystem has both abiotic (nonliving) and biotic (living) components. The biotic components of an ecosystem, or all the organisms living in it, taken together, comprise an ecological community. The abiotic components can be separated into inorganic and organic, whereas the biotic components are usually classified as producers, consumers, and decomposers. Producers, some times called autotrophs, are the green plants that trap solar energy and convert it into chemical energy. Consumers, or heterotrophs, are all the animals, that either eat the plants or one another; all heterotrophs are thus directly or indirectly dependent on plants for energy. Several layers of consumers are recognized (primary, secondary and tertiary) depending on whether they eat plants directly or other herbivorous or carnivorous animals. Decomposers, also heterotrophs, are often bacteria and fungi; they function in the ecosystem by breaking down plant and animal material into simpler components and thereby returning nutrients to the autotrophs, decomposers are therefore essential in recycling matter within an ecosystem."

\(^{43}\) Conway's use of the concept sustainability differs from the way sustainable is used in the definition of sustainable development. In the latter definition the influence of stress or shock is not the subject, but rather (the stress is on) a similar or better resource endowment for future generations. Compare Section 3.1: 'sustainable development is a form of development which leaves the next generation with a similar, or better, resource endowment than that which the present generation inherited' (Pearce, 1989). The term 'resilience' will be used when Conway speaks of sustainability, while 'sustainability' will be used as in the definition of Pearce.
1) productivity: output of valued product per unit of resource input; common measures of productivity are yield per ha (e.g. kg/ha), or an income measure such as gross margin per ha (e.g. $/ha), or production per labour day of a household member (e.g. kg/day or $/day), etc.

2) stability: constancy of productivity in the face of small disturbing forces arising from normal fluctuations and cycles in the surrounding environment;

3) resilience: ability to maintain productivity when subjected to stress or shock;

4) equitability: evenness of the distribution of the product among the beneficiaries of the agro-ecosystem, e.g. the farm-households, or the population of a village, region or nation.

Humankind is the only population that has developed the ability to manage an (agro-)ecosystem for its own benefit. One could say that by managing the ecosystem, humankind creates economic systems. In order to increase the social value, humankind strives to develop these economic systems. In order to study the interrelations between socio-economic development and the behaviour of agro-ecosystems, it is important to identify and study factors and processes that affect the four properties defined above.

In the production and consumption of goods and services, the relations between the economic process and the physical world (with regard to the use of energy and materials) are governed by the first two laws of thermodynamics. The first law is often referred as to the 'law of conservation of matter and energy.' As a consequence, "When materials - minerals, fuels, gases, and organic materials - are extracted and harvested from nature and used by producers and so-called consumers, their mass is not altered in these processes except in trivial amounts. Materials and energy residuals are generated in production and consumption activities, and the mass of the former must be about equal to that initially extracted from nature; accordingly it is basically deceptive to speak of the consumption of goods." (Kneese & Bower, 1979: 5-6). So, if the economic system is bounded by the environment with which it has input (energy and resources) and output (energy and residuals) relations, "Each increase in the production levels of physical goods in our economy has two effects: (1) a corresponding increase in the amounts of material

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44 A formal definition of the first law of thermodynamics is "the change in the internal energy of a system is equal to the net energy flow across the boundaries of a system." (Eden et al., 1981: 22).
inputs and energy from the environment and (2) a corresponding increase in the waste loads placed on the absorption capacity of the environment." (Nijkamp, 1977: 12). Economic growth in terms of physical goods must imply additional extraction of resources from the environment and increased waste.

While the first law of thermodynamics has an optimistic message for the economy - energy and matter cannot get lost - the second law is basically pessimistic. The second law applies to the flow of energy in a system and introduces the concept of entropy. Entropy is defined as a measure of the unavailable energy in a system. Total energy can be divided into available and unavailable energy. Available energy is spread unevenly in highly ordered forms, such as the kinetic energy of a waterfall or the potential chemical energy of fossil fuels. These qualitative properties make it useful for conversion into (mechanical) power for use by humans. In contrast, energy that is unavailable is spread evenly, or completely dissipated as waste heat in the system, which prevents it from being used as a source for power. When fossil fuels are burned, the heat dissipates into the atmosphere at a low temperature. Entropy is a measure of the qualitative state of energy in a system. The second law can be defined as follows: heat flows by itself only from the hotter to the colder body. Energy used in an economic process results in waste, and the energy usefully used is dissipated after use, leaving the system with a higher state of entropy: "Even though energy is conserved in a closed system (first law of thermodynamics), the system tends toward an energy state corresponding to that of minimum usefulness (high entropy, second law of thermodynamics)." (Krenz, 1976: 70).

According to Georgescu-Roegen (1971 & 1979), the concept of entropy can also be applied to matter, although in a physical sense there is no need for this. When matter, in analogy to energy, is used in economic processes (production and consumption), it finally ends up - after depreciation - as less useful waste products, even after eventual re-use. Each economic process, which is dependent on the environment for energy and matter, transforms this energy and matter, 'resources', irrevocably and irreversibly, from a useful state (low entropy) to a

\[\text{45 A formal definition of the second law of thermodynamics is: "no self-acting and cyclic device (unaided by any external agency) can make heat pass from one body to another at a higher temperature." (Eden et al., 1981: 12).}\]
useless state (high entropy), 'waste'\textsuperscript{46}. The economic system uses low entropy resources from the environment so that the human population, and its related physical elements, like producer and consumer goods are maintained in a low entropy state. In order to do so, it has to give back to the environment high entropy waste. In its turn the environment maintains itself by utilising the flow of available energy from the sun to build up low entropy resources (matter and energy). If the waste generation of the economy is faster than the regeneration capacity of the environment, the economic process will cause irreparable damage to the environment. The following quotation from Daly (1979: 74 & 76) is pertinent.

"We have two sources of low entropy: terrestrial stocks of concentrated minerals, and the solar flow of radiant energy. The terrestrial source (minerals in the earth's crust) is obviously limited in total amount, though the rate at which we use it up is largely a matter of choice. The solar source is practically unlimited in total amount, but strictly limited in the rate in which it reaches the earth. These means are finite ... terrestrial stocks can, for a while at least, be used at a rate of man's own choosing, that is, rapidly. The use of solar energy and renewable resources is limited by the fixed solar flux, and the rhythms of

\textsuperscript{46} The following note in Barbier (1989: 61) is useful: "As Kneese & Bower (1979: 6) indicate, the non-usefulness of a residual in the economic process can also depend on such factors as the state of technology and the relative costs of using the residual as a recycled input:

'A residual is a non-product (material or energy output), the value of which is less than the costs of collecting, processing and transporting it for use. Thus, the definition is time dependent, that is it is a function of (1) the level of technology in the society at a point in time and (2) the relative costs of alternative inputs at that point in time. For example, manure in the United States is now a residual, whereas thirty or so years ago it was a valuable raw material.'

Assuming, in the long run, that the relative scarcity of natural resources yields favourable relative costs for recycling and that the required technology is available, then it might be theoretically possible to recycle all residuals. Nevertheless, the point of the second law is that, even under these ideal conditions, complete recovery and recycling of all waste residuals, including material residuals, remains a physical impossibility. As material inputs are continuously re-used in the economic process, there is bound to be losses of gasses, particulate dust, and even dry and wet solids. Moreover, even if collecting, processing and transforming potentially recoverable material residuals is economically and technologically feasible, the recycling will require new inputs of energy and material that yield other irrecoverable wastes (e.g., the carbon, hydrogen and waste heat from fossil fuels used in recycling) and result in some loss of the recycled waste (particulate dust or gas)."

Of course, recycling can considerably prolong the availability of material inputs; a recovery factor of 0.8 of a certain input makes five times the original amount of the input available.
growth of plants and animals, which in turn provide a natural constraint on economic growth. But growth can be speeded beyond this constraint, for a time at least, by consuming geological capital - by using up the reserves of terrestrial low entropy ... The throughput flow maintains or increases the order within the human economy, but at a cost of creating disorder in the rest of the natural world, as a result of depletion and pollution."

Barbier (1989: 55-57) presents an 'alternative' view of the economic-environmental interaction. Ecology has stressed the complexity and diversity of ecological relations and has clarified the notions of ecological stability and resilience in the face of human disturbance of (agro-) ecosystems. Thermodynamics provides economics with the methodology for depicting the 'throughput' of materials and energy from the environment into the economic process and then back into the environment. The first law of thermodynamics allows the economic system and the environment to be viewed together as a closed circular system of energy and material transformations. The second law can be analogously applied to depict this process as an irreversible transformation of ordered (low entropy) material and energy into disordered, dissipated and therefore useless (high entropy) waste. The important role of the laws of thermodynamics in the economic process is also stressed by Dasgupta & Mäler (1995: 2388-2390).

Moreover, as the environment is the source of the resources transformed by the economic process, and the recipient of its wastes, the net effect of this transformation is to maintain or increase the order in the economic system at the expense of increasing disorder (degradation) of the environment. At the heart of these alternative views is the recognition of a new natural-resource scarcity problem: that increasing environmental degradation (or disorder) may, under certain conditions, threaten ecological productivity, stability and resilience, and thus sustainability. By supplying more and more resources to the economic process and by having in turn to absorb the resulting waste, the environment can no longer maintain indefinitely the same degree of ecological activity. Ecosystems may eventually break down if the environment is continually disrupted and cannot maintain its resilience. Under such circumstances, the opportunity costs in environmental terms of supplying the material needs of the economic systems with terrestrial resources is increasing ecological unsustainability. Or, more bluntly put, what we gain in material welfare, we lose in environmental wellbeing. In essence, this dynamic natural resource scarcity problem stems from the physical dependency of the economic process on its natural surrounding environment - not just as a source of material and energy inputs but also as an assimilator of waste, and the provider of ecological functions
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crucial to the maintenance of economic activity and supportive amenity values, welfare and life in general.

This brings to us the problem that economics does not have an existence theorem (Pearce & Turner, 1990: 42). Such a theorem would demonstrate "whether any particular economy is consistent with the natural environments which are necessarily linked to that economy." Also, it would "relate the scale and configuration of an economy to the set of environment-economy interrelationships underlying that economy." As economics lacks such a theorem, particular economies, ranging from the theoretical constructs of a free-market economy to a centrally-planned economy, as well as in relation to empirical manifestations of real world economies, run the risks of running down the functions of the natural environment.

Economies might survive for long periods in disequilibrium with their natural surroundings, but if we are interested in sustainability in the long run, it is important to investigate the conditions for the compatibility between economic systems and ecosystems. In this respect, Pearce & Turner (1990: 35-41) present a flow chart of what they call the 'circular economy', in which they show graphically the main relations between the economy and the environment.

The 'alternative' view of natural resource scarcity can be described in a model (Barbier, 1989: 101-104 & 110-115). Basically, explicit relations are defined (starting in a theoretical and qualitative way, but eventually progressing to a quantitative and empirical way) between the economic system and the environment, both in its function as provider of inputs (material and energy resources, low entropy), as well as in its function as waste (again material and energy, but with a higher entropy) recipient. Obviously, although not easy, it is possible to formulate such a model in theory. For an interesting and extensive example, incorporating welfare economics, see Krabbe (1989). However, it would be much more difficult, if not impossible, to test such a model in reality. This is also obvious from Barbier (1989), who does sketch such a model, but where the empirical 'examples' are a far cry from his model. However, such a model could provide a framework for analysing the relations between economic development and the environment. An attempt to formulate

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47 See Sections 4.5 and 5.2.2, and Chapters 6 and 7. The WAU programme for Costa Rica researches ways of modelling the relationships between the ecology and the economy in the context of the natural resource land and the sustainable use of that resource, using, among others, crop growth models, nutrient balances and economic models at both the farm and the sub-regional level.
economy-environment interaction models for sustainable development, with applications at the regional level, can be found in Van den Bergh (1991).

3.3 Cost-benefit analysis

Cost-benefit analysis (CBA) is a widely accepted tool for the appraisal of investment projects and programmes from a financial, economic and social point of view. CBA is firmly rooted in one tradition of economic theory: welfare economics. In a sense it is a form of applied welfare economics, and therefore its theoretical basis and limitations are those of theoretical welfare economics (Lal, 1974).

The question here is whether CBA is relevant for land use planning. It is, especially for decisions with regard to investment in land, e.g. irrigation and drainage (Samana, 1979), soil conservation measures (Anderson, 1987), or investment in a long-term use, perennial crops (Polman et al., 1982). CBA can be useful for deciding whether or not to invest, or for comparing the attractiveness of different alternatives, both for the individual land user, as well as for a national/(sub-)regional organisation (e.g. planning institute). However, CBA is not without problems, both in theory as well as in practice. From the theoretical point of view, problems can arise with choosing a correct objective, especially if no single objective exists, e.g. efficiency and/or equity, with externalities, and with the valuation of both inputs and outputs (shadow prices), and the choice of the discount rate. In practice, there are problems with data collection and the arbitrariness of many assumptions. Adoption of different assumptions can make a project acceptable or not. As the parties involved in project appraisal often have different stakes in the outcome of an appraisal, there is a danger of CBA being misused.


49 A lot could be gained by being as explicit as possible with regard to all assumptions and (methods of) calculation(s), and adhering to certain standards so as to make the appraisals commensurable.
These problems are compounded when considerations regarding the 'sustainability' of development also have to be taken into account. Van Pelt et al. (1990) argue in favour of restricting the concept of development to non-negative changes in social welfare over time, in which social welfare is considered to have two components: man-made products and services and the consumption of environmental amenities, i.e. services that directly influence the well-being of man. Such a development concept is less complicated than the much broader concept of Pearce et al. (1990). The environment provides three kinds of functions to humankind: material and energy inputs, (including renewable, non-renewable and semi-renewable resources), assimilation of waste products, and a stream of natural services, the quality of which is essential for supporting economic production and human welfare. Sustainability is then defined by Van Pelt et al.(1990: 6) as the continued and sufficient availability of these environmental goods and services (the environmental functions) over time\(^{50}\). In the remainder of their paper, CBA is analysed with respect to its ability, also in comparison to multi-criteria analysis, to handle sustainability issues. The last theme is elaborated more profoundly in Van Pelt (1993).

There are many relevant publications on issues relating to CBA and sustainability, too many to mention all. Especially relevant are the following. Pearce et al. (1988) and Barbier et al. (1990) address aspects of including a sustainability constraint in CBA and the possibility of pursuing 'shadow' projects in a programme of projects to repair/avoid environmental damage by other projects of the programme. Pearce et al. (1990) discuss the appropriate rate of discount for projects for sustainable development. They argue against using lower rates as this would be arbitrary as well as stimulate overall economic activity. The rate of discount is in the first place a capital rationing device and should be used as such. It would be better to value environmental benefits and costs properly. For aspects of valuation, see Hufschmidt et al. (1983) and Dixon & Hufschmidt (1986), and for a 'popular' version in the context of CBA, Dixon et al. (1988). Special emphasis on the economics of dryland management can be found in Dixon, James & Sherman (1989 & 1990). Recent texts containing contributions with regard to the valuation of

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\(^{50}\) Van Pelt et al. (1990: 8-9) do not consider the 'constancy of natural capital' as a necessary condition for sustainable development as do Pearce, Barbier and Markandya (1990). They allow for the possibility of substitution between man-made capital and natural capital, provided this is done with great care, and irreversibility and risks are taken into account properly.
environmental resources are Hanly & Spash (1993), Layard & Glaister (1994), OECD (1994) and Weiss (1994).

3.4 Farm management, production economics and household economics

The principles of farm management and production economics are long established and largely based on a marginalist approach. The theory behind these principles could be called a 'neoclassical theory of farm production'. Important references are Heady (1952), Dillon & Hardaker (1980), Nakaijma, (1986), Upton (1973, 1976 & 1987), and Ellis (1993).

Basic assumptions (Ellis, 1993: 18) are a single goal ('profit maximisation') and resource constraints of the individual farm. Furthermore, only a single decision maker is permitted, and dissension among the farm household members is certainly not allowed for. Other assumptions are competitive markets for inputs and outputs and an unlimited supply of working capital. On the basis of the idea that farmers can vary the level and kind of inputs and outputs, and on the basis of the (physical) relationships between inputs and outputs ('production function'), between inputs and inputs ('method or technique of production'), and between outputs and outputs ('enterprise choice'), Ellis (1993: 42-43) distinguishes seven so-called principles: 1) variable versus fixed resources, 2) diminishing marginal returns, 3) substitution, 4) enterprise choice, 5) most limiting resource, 6) opportunity costs, and 7) comparative advantage. Compare with Dillon & Hardaker (1980: 3-6).

A first question is whether the above theory has any relevance for farming in developing countries. Most of the assumptions are certainly not valid in a strict sense. A number of empirical studies, especially in India (e.g. Hopper, 1965; Chenareddy, 1967; Sahota, 1968; Saini, 1969), but also in Africa (e.g. Norman, 1974 & 1977), have been carried out as a result of the 'poor but efficient' hypothesis of Schultz (1964). The results are mixed, also because of theoretical problems with the concept of production function and its empirical verification or falsification (Ellis, 1993: 67-76, see also Section 5.2.4). Apparently the notion of the 'optimising peasant' (Lipton, 1986) in its strict interpretation is not generally valid. However, it is clear that there is a strong element of economic calculation on the part of farm households. Their decision making can be considered as conditional or constrained optimisation. Farmers' approaches to such decision making often take the form of cautious optimisation over a period of time and sequential decision making within years (Huijsman, 1986: 272). For analysts, trying to
understand farm household decision making, a precise and realistic description of its goals, options (e.g. between crops and technologies, but also possible adaptations to changed circumstances while the crop stands in the field) and constraints (both at the farm level as well as constraints imposed by the biophysical and the socio-economic ‘environment’) are a necessary and important first step. Helpful theories for understanding peasant behaviour under different sets of assumptions include the ‘profit maximising peasant’, the ‘risk-averse peasant’, the ‘drudgery-adverse peasant’, the ‘farm household peasant’ and the ‘sharecropping peasant’ (Ellis, 1993). However, it should be emphasised that reality is often far too complicated to be encompassed by one of these theories. Other important topics include the role of family labour (differentiated according to sex and age) in the farm household, farm size and technical change. On the other hand, in order to be able to create workable land use decision models, as in the present research, many simplifying assumptions will have to be made.

Especially relevant for the present research (in which land use is analysed at the farm level also) are the theories of household economics, which form the basis of the above mentioned theory of the ‘farm household peasant’. Household economics studies the production of intermediate non-market goods with purchased market goods and scarce household resources (money, time, and other variables). The intermediate non-market goods are consumed in combinations that generate maximum utility for the household. Household economics (Barnum & Squire, 1979; Singh, Squire & Strauss, 1986a & 1986b; Low, 1986; Lambert & Magnac, 1994; Muller, 1994; Coyle, 1994; Becker, 1994) could guide the analysis of land use at the farm level away from too much attention to the farm production side of farm households, neglecting the household production and consumption aspects.

However, assumptions of household economic models are not always tenable. For example, independent decision making by one sole decision maker within the household is often not the case. Households often belong to larger extended families or groups of households. Also, households are imbedded in local social structures. Furthermore, men and women inside households often make their own, sometimes conflicting, decisions regarding labour allocations or the use of other household resources (e.g. food). These critical remarks are well described in Hunt (1991) and Ellis (1993: 180-187). Alternative approaches, based on bargaining and collective decision making, can be found in Brossolet (1994), Bourguignon & Chiappori (1994) and Caillavet (1994). Udry (1994) has developed a model for intra-household resource allocation, based on a game theoretical model reaching a Gournot-Nash equilibrium.
He argues that the allocation of resources across productive enterprises within certain households is not Pareto efficient, and thus rejects both cooperative bargaining approaches and the more general model of efficient household allocations of Chiappori and others (e.g. Bourguignon & Chiappori, 1994). In order to develop more of these types of models, which would be appropriate for analysing households in particular areas, economists should turn more often to relevant empirical field studies. Next to agro-economic surveys, important sources would be (economic) anthropological or sociological studies. An interesting example is Netting (1993), in which the functioning of small households in various agricultural systems under changing circumstances is interpreted from anthropological, ecological and economic viewpoints.

In the light of the above theories of peasant behaviour, the simple approach of land evaluation, by which land use types are compared for their suitability with regard to land units, is grossly inadequate, at whatever level of detail, as a basis for land use planning. As long as the land use types are not seen as parts of farm systems and the farm household is omitted as a unit of decision making, land evaluation can only be useful in the sense that it provides information about technical coefficients with regard to (potential) production possibilities. See also Sections 2.3.2 and 4.4.

At this point, it makes sense to review a number of farm level models for explaining soil degradation. Two main types can be distinguished. Those that make use of continuous production functions which act as a constraint on an objective function (a measure of income or utility) and those that opt for a (dynamic) (non-)linear programming approach. A typical example of the first approach is Barbier (1990), but other references include McConnell (1983), van Kooten et al. (1990), Barrett (1991), Ehui & Spencer (1993) and Oramzem & Miranowski (1994).

Barbier postulates a production function with two arguments, external inputs (e.g. fertiliser) and the soil depth, valid in all periods (e.g. years). Production causes erosion and therefore decreases soil depth, but the soil depth can be increased by using other inputs (e.g. soil conservation measures). Given these conditions, applicable in all periods, the farm maximises a discounted (at a farmer's discount rate) profit measure over all periods. The solution of the model implies that a) the value of the marginal product must be equal to the total costs (external inputs plus costs in terms of worsening soil erosion), and b) the costs of soil conservation must be equated with the additional value it generates by
Economic theories of land use

controlling soil erosion\(^{51}\). This elegant approach is useful for obtaining theoretical insights into the nature of soil degradation and conservation. However, because of many simplistic assumptions, these models are difficult to test empirically. This is illustrated in Barbier (1990), by providing only verbal arguments to make the model plausible; the model itself is not illustrated empirically.

The programming approach can be found in Kramer et al. (1983), Miranowski (1984), Johnson et al. (1991), Young et al. (1991), Day et al. (1992), Wossink et al. (1992), Sang et al. (1993), Wossink (1993), Alfaro et al. (1994), Verhoeven et al. (1994), Cárcamo et al. (1995), Oglethorpe (1995), Schipper et al. (1995) and Teague et al. (1995), as well as the case study in Chapters 6 and 7. A discussion of this approach is deferred to Section 5.2.2.

Recently, a number of studies have appeared regarding soil conservation and land management at the interface of soil science and (agricultural) economics. Although not all studies mentioned here are confined to the farm level, they are also relevant for farm level decision making, as well as issues at project, regional or national level. Sheng (1989) discusses technical and economic aspects of soil conservation for small farms in the humid tropics, while Hudson (1991) studies the reasons for success or failure of soil conservation projects. Lal & Pierce (1991) present studies on soil management for sustainability. Sfeir-Younis & Dragun (1993) discuss technological, economic and institutional aspects of land and soil management very comprehensively, and based on long practical experience. De Graaff (1993) addresses economic aspects of soil conservation and sustainable land use at the watershed level, while taking into account the role of farm households in soil management. Finally, Syers & Rimmer (1994) present papers on soil science and sustainable land management in the tropics.

3.5 Other theories relevant for land use

In addition to the above theories, a number of other economic theories, approaches or problem areas are relevant for land use decisions: regional economics and comparative advantages, institutional aspects, micro-macro

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\(^{51}\) Solving the Hamiltonian of the problem, one also obtains a shadow price of the soil in each period. In the optimal solution this shadow price, or the implicit cost of soil loss, must grow at the rate of discount less the soil's contribution to current profits (Barbier, 1990).
linkages and aggregation problems, and linkages between sectors. Each will be described in the following sections.

3.5.1 Regional economics and comparative advantage

Regional economics is concerned with the development of regions as territorial parts of a national economy. Relevant questions are: why are there differences within a country with regard to production structure, income and employment and their respective rates of change? Answers lie in causes like different locations, different resource endowments (natural, human and infrastructure), different histories, answers which could be conveniently summarised under the heading of comparative advantage. Generally speaking, each area tends to produce those products for which it has the greatest ratio of advantage or the least ratio of disadvantage when compared to other regions (Barlowe, 1986: 219).

Comparative advantage in a regional context can be compared to comparative advantage in the context of international trade. In the latter case, a country tends to specialise in the production of those goods for which it has the greatest ratio of advantage compared to other countries. However, a difference between the two types of comparative advantage is that in the regional variant of comparative advantage labour and capital are supposed to be mobile, and land not, while in the international variant only capital is supposed to be mobile, and labour and land not. Notwithstanding, this difference does not, in principle, affect the working of comparative advantage.

In the context of land use planning, it is important to realise that the principle of comparative advantage might 'overrule' the suitability assessments, both in physical as well as in economic terms, for the use of certain land units. An area might be very suitable for a certain crop, but if another area is even more suitable (because of, for example, its climate or soils, or because it is closer to the markets) for the same crop, it might be used for a crop for which it is somewhat less suitable. In this respect, comparative advantage is also the force behind the classical location theory of agricultural production of Von Thünen (1850).

Comparative advantages should not be interpreted in a static way. These advantages can and do change, also through government action such as investment in infrastructure or education. Another example of government interference with comparative advantages between regions, which may be less beneficial, is 'pan-territorial' pricing. This means that, through state intervention, a product receives the same price everywhere in a country irrespective of transport costs, as has been the case in Zambia until recently.
For a brief outline of different theories of regional economics (and planning), see Appendix 1.

3.5.2 Institutional aspects

For each particular land use planning exercise, specific objectives are required. In general, they include efficiency in the use of scarce natural resources, equity between groups in the society with regard to the distribution of benefits and costs of the use of resources, and conservation of those resources for future use. Between those objectives there are often conflicts and trade-offs. It is also likely that there will be conflicts of interest (Pen, 1968) between different groups of land users concerning the distribution of the benefits and costs of the use of land (Blaikie, 1985; FAO, 1989; Riddell, 1985). Examples of such opposing groups, each having their own goals and interests, are land owners and tenant farmers (Pen, 1968), big and small farmers, commercial plantation owners and adjacent subsistence farmers (Blaikie, 1985), richer and poorer pastoralists (Little, 1987), farmers, pastoralists and tourists (Campbell, 1981), and rural (subsistence) farmers and city dwellers (Lipton & Longhurst, 1989). The goals of the different groups may also be different from 'national' objectives as formulated by the government. As a result, governments often disagree with farmers over the best use of land. Another, related, source of disagreement could originate from differences between analyses based on private financial considerations and analyses from a national-economic or social point of view (Helmers, 1977; Gittinger, 1982; Kuyvenhoven & Mennes, 1985).

Explaining land degradation requires a comprehensive, multi-level approach (de Graaff & Schipper, 1991). In this respect, Blaikie & Brookfield (1987a) refer to a ‘chain of explanation’ of causes of land degradation. Farmers (or other land managers) may use inappropriate technologies, but their practices are determined by local ecological conditions, by the resources available to them, and by other users (e.g. other users of open access or common property resources). These local communities are affected by the wider agrarian society and regional
authorities, which influence the distribution of land rights, education and extension, programme implementation, etc. The last links in the chain constitute the national state, responsible for policies, administration and regulation, and the world economy with its fluctuating commodity prices, interest rates affecting debt services, etc. It is usually inadequate to ascribe single causes to degradation. There is a hierarchy of causes, each level of which has to be addressed separately (Blaikie, 1990).

3.5.3 Micro-macro linkages and aggregation problems

One of the major problems with land use planning is that it is primarily applied to the land units of a region, thus at a higher level than the farm, while abstracting from the farm system as a basic decision making unit. Three issues are important. At the regional level land use is often planned without taking into account the reactions of farm households which are where the real decisions are made concerning land use. Furthermore, as individual farmers have resources at their disposal in proportions different from the aggregated resources of a region this leads to an aggregation bias. Lastly, variables that are exogenous at the micro level might be endogenous at higher levels. This applies especially to product and factor prices. These problems are also known from efforts to build (linear programming) models at a national or regional level and are discussed extensively in Hazell & Norton (1986: 139-148); see also Sections 4.5 & 5.1). The aggregation issues are also addressed in the context of the case study (Chapters 6 & 7).

The problems mentioned here could be conveniently divided into differences between a micro and a macro analysis. In economics, the relations between analyses at the micro and at the macro level are theoretically among the more difficult problems, compounded here, in the context of land use planning, because different regions are also involved (comparative advantage). These relations have yet to be solved in a satisfactory way, certainly for practical situations.

Theoretically there are possibilities for an approach through models at different levels. One could develop different models for the farming systems of a region, and incorporate the results of these models, with regard to the objectives and the use of regional resources and constraints, as activities in a model at the regional level. Until now, this approach has met with little success, see Hazell & Norton (1986). Much further research is necessary in this area, to which the present research hopes to contribute.
3.5.4 Linkages between sectors

Too often, in (regional) agricultural planning, the agricultural sector is isolated from the rest of the economy, while certain developments outside this sector are highly relevant for the sector itself. A main example is, of course, the marketing of agricultural products and the prices obtained, but other important issues relate to employment alternatives, and savings and investment opportunities. In economic terms, markets for factors of production are linked between sectors. Therefore wages and interest rates in one sector are not independent from those in other sectors. A proper analysis would require a general equilibrium approach, as partial approaches do not adequately take into account the relations between economic sectors; or at least a so-called ‘multi-market’ analysis, in which the consequences of policy changes on related products can be analysed (Braverman et al., 1987).

However, general equilibrium models are not without problems. One of the disadvantages of such models is that parameters are based on statistical estimates (which are not always possible given data limitations) and that they are not able to incorporate a priori technical information about, for example, the relation between inputs and outputs or the complementarity of inputs (e.g. Bauer 1988; Keyzer, 1982 & 1990).

Recently, attempts have been made to combine non-linear optimisation models, modelling the supply side of the agricultural sector, with a general equilibrium model; see Keyzer (1990) for a theoretical outline, and SOW (1990a & 1990b) for an application. In this approach, use is made of (continuous) production functions, cost and profit functions and of duality theory. For an explanation of the latter concepts, see Chambers (1988). Another line of research attempts to introduce price responsive demand and factor supply functions in (linear) programming models (Hazell & Norton, 1986). For applications, see, for example, Duloy & Norton (1973a), Kasnakoglu & Bauer (1988) and Celis (1989). Other research concentrates on multi-level modelling, optimising farm level models after which the results are incorporated into sector models in an iterative way (e.g. Hanf & Noell, 1988). Goreux & Manne (1973) provide a number of papers on earlier multi-sector and multi-level models.

In view of the objective of the present research, namely the elaboration of an improved methodology for land evaluation and land use planning, which makes extensive use of a priori technical information, the emphasis will be on linear programming models. The models follow a two-level approach: the farm and the (sub-)regional level, modelling the supply of agricultural products at these levels. The linkages between these
levels and with other economic sectors, including the demand for agricultural products, will be taken into account where relevant and possible, given data and time limitations.
4 METHODS OF LAND USE ANALYSIS AND PLANNING

4.1 A skeleton model of the agricultural sector

Land use planning has been outlined in Section 2.1. Here, methods of land use analysis and planning\(^{52}\) will be sketched, incorporating land evaluation and farming systems analysis. However, as land use planning is considered a form of regional agricultural planning, regional agricultural planning is introduced first (Section 4.2). This is followed by an introduction to the so-called LEFSA sequence as a framework for land use planning (Section 4.3). In Section 4.4 possible improvements to land evaluation as a tool for land use planning from an economic point of view are proposed. The chapter finishes with a discussion of a number of aspects of land use analysis and planning as such.

In order to place the whole discussion about these different forms of analysis and planning of the agricultural sector in a proper perspective, it is useful to present a skeleton model of the agricultural sector (Moll & Schipper, 1994: 2-4).

In Figure 4.1, the right-hand side of the model is structured according to the various actors in the agricultural sector and their occupations: policies and policy measures affect operators in markets, services and infrastructure, who together determine the direct socio-economic environment in which farm households, or primary producers in general, operate. On the left side of Figure 4.1, the natural resources and the state of technology determine the types and technology levels of crop\(^{53}\), livestock, forestry, and fishery activities. As these activities use land, it is customary to call them land use types (LUTs). LUTs combined with land units (LUs) form land use systems (LUSs). Each land use type (LUT) has subtypes which are classified according to technology. A particular

\(^{52}\) On the differences between analysis and planning in the context of land use, see Sections 4.2.3 and 4.5.

\(^{53}\) Either individual crop activities, for those crops which are grown in monoculture regardless of the preceding or following crop, or a combination of crops for fixed rotation or combination patterns.
combination of a land unit (or parcel\textsuperscript{54}) and a LUT with a specific technology is called a LUST\textsuperscript{55}.

The farm households make a selection of the LUSTs on the basis of their resources and preferences, and they do so under influence of the socio-economic environment. The total output of the agricultural sector (in terms of primary products) depends on the actual selection of the LUSTs by the farm households. This output consists of a) the types and quantities of products, and b) the negative or positive contribution to determinants of the sustainability of agricultural production, thereby affecting future production possibilities. The farm households are thus the final decision makers in agricultural production, but their behaviour is influenced by the biophysical environment on the one hand and by the socio-economic environment on the other hand.

\textsuperscript{54} A parcel can be defined as a land unit within a farm system. In Appendix F of the \textit{FARMAP User's Manual} (FAO, 1986), a hierarchy of farm, parcel and plot is noted. A farm is defined as "A collection of resources usually associated with specific land units managed by a single decision maker (or group) for the primary purpose of crop, livestock, fish or forestry production." A parcel is seen as a part of a farm and defined as "A single piece of land having the same tenure and physical characteristics (including irrigation facilities)." Finally, a plot is "The part of a parcel devoted to a specific activity." To be complete, an activity is defined as "A process using a technology that combines inputs to generate particular outputs for sale, barter or domestic use. An activity can be independently analysed from an economic viewpoint. Activities are classified in FARMAP as plant, animal, special, mixed, domestic, general farm, non-farm or capital formation activities." In the terminology of the present study, crop activities can be compared with LUSTs (Land Use Systems & Technology, see note 55) and animal activities with APSTs (Animal Production System & Technology, see Section 5.3). It is useful to relate the FAO (1986) definitions, reproduced here for easy reference, with those in Sections 2.1, 2.3.3 and 4.4.

\textsuperscript{55} A land use system (LUS) is defined as "a specified land use type on a given land unit", see also FAO (1983: 228) and Fresco \textit{et al.} (1992: 164). The T in LUST is added to LUS to emphasise technology as the main factor for distinguishing 'sub' land use systems within a land use system. For example, if maize cultivated on land unit \textit{x} is a LUS, then maize with 100 kilos urea on land unit \textit{x} is one LUST, while maize with 200 kilos urea on the same land unit is another LUST. The concept of LUST, or a 'Land Use System with a defined Technology' is described in detail in Jansen & Schipper (1995).
Methods of land use analysis and planning

BIOPHYSICAL ENVIRONMENT

Regional level
- Natural resources and environmental factors
  - land and water resources
  - climate: temperature, rainfall, radiation, wind
  - topography
  - pests and diseases

- Actual and potential combinations of land units, land use types and technologies (LUSTs)
  - crop LUSTs
  - livestock LUSTs
  - forestry LUSTs
  - fishery LUSTs

SOCIO-ECONOMIC ENVIRONMENT

Policy makers at national and sectoral levels
- policies towards roles of agriculture
- policies towards utilisation of natural resources and sustainability
- interventions in markets, services and infrastructure

Policy makers and operators in public and private institutions and enterprises
- markets of resources, inputs, agricultural products, consumer and capital goods
- services: extension, research, education etc.
- infrastructure: roads, irrigation works,

Farm households
- resources (land, labour including management and knowledge, capital)
- objectives

- decisions regarding the utilisation of resources for a combination of crop, livestock, forestry and fishery LUSTs (and off-farm activities)

Agricultural production
- types and quantities
- determinants of sustainability

Natural resources

Markets

Source: Moll & Schipper (1994: 4)

Figure 4.1 The agricultural sector
4.2 Regional agricultural planning

In this section regional agricultural planning will be outlined. First a general introduction is given, followed by some remarks on the concept of a region (Section 4.2.2) and on phases in planning (Section 4.2.3). A particular form of regional agricultural planning - 'comprehensive resource based' - will be introduced (Section 4.2.4), together with a methodological approach to this form of planning, the so-called 'pragmatic' model. Finally some remarks will be made on project and programme identification (Section 4.2.5) and on policy implications (Section 4.2.6).

4.2.1 Background

Regional agricultural planning can conveniently be introduced by a lengthy quote from Fresco et al. (1992: 11-13):

"Regional agricultural planning, and, consequently, land use planning, are specific forms of intermediate level planning of sectors and regions within the national economy. Intermediate level planning may be defined as planning of sectors and regions with a view to bridging the gap between general macro-planning and specific project planning. Macro-planning sets, among other things, guidelines for sectoral growth, but usually does not deal with investment projects and their spatial distribution. Project planning goes into great detail of costs, benefits, organisation and financing, but takes as given the broader socio-economic framework in which the project operates. In practice, project planning is often not related to the national framework and tends to lose sight of this broader socio-economic perspective. Proper identification and priority ranking of projects require a middle ground which is specific enough to generate project proposals and broad enough to play a role in the national context.

Regional agricultural planning considers the agricultural sector within one region. The justification for such a type of planning is that in most developing countries agricultural activities are very important, especially at the regional level, because often the largest part of the employment and of the income is generated within the agricultural sector, certainly if agro-processing is included. Furthermore, the regional approach in agricultural planning provides the possibility to take into account specific environmental conditions and therefore to arrive at realistic identification of projects.

However, it should be avoided to analyze the agricultural sector of a region too much in isolation from other sectors and regions of a country. If done so, it might overlook important linkages with, and constraints and opportunities for development in, other economic sectors, as well as comparative advantages elsewhere in the economy. Also, development possibilities in the agricultural sector of a region are dependent on developments in the other sectors and regions.
Regional agricultural planning is concerned with the following types of questions: Which crops are most suitable (in view of the objectives, opportunities and constraints) in a given region? What are the advantages of a region in comparison to other regions? What interactions with other regions are important? What are the implications of alternative land uses for income, income distribution and employment? What farm types would be required and are possible? What are the relations between different crops and animals? Would a land reform be advantageous and for whom? What amount of inputs are necessary? How is the marketing to be organised? Is it possible to set-up an agro-processing industry? What physical and institutional infrastructure is required? Which specific projects and programmes are required? What are the necessary policy changes?

Most forms of regional agricultural planning start with a diagnosis of the present situation and then try to identify possible future developments, taking into account the available resources, for example natural resources, like soils, climate and location; population resources, for example types of labour; capital resources, for example existing processing plants and other capital goods, national or local government budgets, and international loans or grants; and the organisation and management capacity of private or government institutions.

In regional agricultural planning the objectives can be derived in part from national objectives, but should be made region - and period - specific. In this context the goals of the farm households in the region play a key role. In general the interest of different groups in society should be taken into account. This is far from simple and constitutes one of the limitations of planning."

It has to be realised that regional agricultural planning, and certainly the 'comprehensive resource based' versions, is rather time consuming and labour intensive (van Dusseldorp, 1980; van Staveren, 1980; Schipper, 1983). Therefore, past experiences with planning have led to the development of a number of alternative approaches with reduced planning efforts (Moll & Schipper, 1994: 6), like the key-sector and key-region approaches (Bendavid-Val, 1975; Waller, 1975; Schipper, 1983) and the process approach (Röling & de Zeeuw, 1983; Zijderveld, 1992). Others, like Chambers (1983), are more concerned with less elaborate and time consuming methods of data collection, for example using 'rapid rural appraisal' instead of surveys (Fresco et al., 1992: 108-117). Neither of these issues will be discussed here.

In general, planning has also been criticised on conceptual grounds. These criticisms can be subsumed under four headings: 1) administration bias, 2) lack of knowledge, 3) uncertain future, and 4) harmony versus conflict. For an elaboration of these points, see Fresco et al. (1992: 181-182).

In consideration of the above criticisms on planning, regional agricultural planning should formulate plans that take into account the
contradictions in society and that are realistic with regard to what can be done, here and now, in view of the limited resources (financial, person-power and implementation capacity) of an administration and the limited capacity to influence autonomous forces in a society (Toye, 1989). Thus, planners have to realise their limitations. Nevertheless, planning is useful and necessary for the acceleration of development (Moll & Schipper, 1994: 7). Obvious themes for planning are the physical and institutional infrastructure, and the creation of the right ‘conditions’ for agricultural development, compare Baum & Tolbert (1985: 27). Besides, a government that does not intervene in markets and does not implement projects and programmes, as a consequence of a lack of planning, creates a situation of ‘laissez faire’. This is not tenable, especially with regard to the agricultural sector, as a wide variety of experiences shows (Timmer, 1988: 301). Such a situation is not in the interest of agricultural development, nor in that of the majority of the population. However, intervention in prices and markets is difficult. In addition to ‘market failures’ in agriculture, there are ‘government failures’ (Timmer, 1988: 325-326). Intervention requires careful analysis, based on both efficiency and equity considerations (Colman & Young, 1989: 206-209), resulting in the right ‘degree’ of intervention.

4.2.2 The concept of a region

As this document is concerned with land use planning as a type of regional agricultural planning it is essential to say something about the concept of a region. In planning at least four types of regions are distinguished: 1) functional regions, 2) administrative regions, 3) homogeneous regions, and 4) planning regions.

Functional regions have an internal cohesion formed by the network of relations and flows of people and goods between parts and the centre of the region. In regional planning this type of region is important for the development of theories like growth pole, growth centre and service centre theories. However these regions often do not have an administrative background, in other words they do not coincide with district or provincial boundaries. This is a disadvantage for planning in practice and certainly for execution of plans. Furthermore, a country cannot be split up completely into functional regions, as these will tend to overlap.

Administrative regions do conform to the last mentioned criteria of complete-split-up and no-overlap for a complete framework of regionalised planning. An advantage of these regions is that much data available (e.g. on population) is based on an administrative division.
Also, government departments are often organised by district or province, which is important for the implementation of a plan. A disadvantage for agricultural planning is that administrative regions are often not homogeneous with regard to natural circumstances and farming systems. This complicates agricultural planning.

Regions which do not differ too much internally with regard to their natural circumstances are called **homogeneous regions**. Such regions simplify agricultural planning. However, it would not be practical to make agricultural plans per homogeneous region because they will not coincide with the administrative structure. This is a disadvantage especially during the implementation of a plan. As a compromise an administrative unit is often chosen as a region for agricultural planning and this region is then subsequently subdivided into homogeneous zones. The agricultural plan for the Matara district in Sri Lanka is an example of such an approach (Polman et al., 1982).

**Planning regions** are regions specially created for the planning and implementation of certain development ideas and policies for example for a catchment area of a river (river basin planning). The Mahaweli project area in Sri Lanka is an example of such a region.

As was remarked in the above quote from Fresco et al. (Section 4.2.1), regional planning - along with sectoral planning - is a form of intermediate level planning between the national level and the project level. The consequence is that a region as an object of planning should not be too small. It should have an impact at the national level. Local level planning or village planning, therefore, cannot be considered as regional planning.

### 4.2.3 Phases in planning

Van Dusseldorp (1980: 6) distinguishes *planning* from *planned development*. Planned development\(^{56}\) is where the course of development is influenced by planning. Planned development is considered to consist of three main phases: 1) plan preparation, 2) implementation and 3) evaluation. Plan preparation can be further subdivided into 1a) goal formulation, 1b) diagnosis of the present situation, 1c) plan formulation.

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\(^{56}\) Dusseldorp (1992: 6-7) considers planned development a cyclic process. This, as well as the different phases in each cycle, is in accordance with a systems approach to planning. See McLoughlin (1970: 92-103) in the case of urban and regional planning, and González et al. (1977a: 92-126) in the case of agricultural sector planning.
and 1d) acceptance of the plan. Van Dusseldorp sees planning as activities occurring within planned development, in particular in the (sub-)phases 1a, 1c and 3.

In general, the terminology of Van Dusseldorp closely follows the terminology of Tinbergen (1956: 10). Tinbergen considers that the procedure of (economic) policy-making could be sub-divided into five phases: A) ascertaining the actual state of affairs, B) finding out whether this state diverges from what is considered to be the most desirable situation, C) estimation of the effects of possible alternative policies, D) taking decisions, and E) execution. Tinbergen calls phases A to C policy planning, while the phases A to D are policy design. So Tinbergen’s policy design concurs with Van Dusseldorp’s plan preparation, while Tinbergen’s policy planning concurs more or less with Van Dusseldorp’s sub-phases 1b, 1a & 1c (in that sequence). Moreover, phase D of Tinbergen coincides with sub-phase 1d of Van Dusseldorp. Of course, phase E of Tinbergen is comparable to phase 2 of Van Dusseldorp. Finally, phase 3 of Van Dusseldorp is not included in Tinbergen’s phases, but could be considered to be included in his phase A: as planning is often seen as a cyclic process, evaluating what happened in the last cycle, should be part of ‘ascertaining the actual state of affairs’.

These phases are not clearly separated in time, but overlap. Furthermore, planning is an iterative process: conclusions reached in later phases may throw new light on conclusions arrived at in earlier ones. For example, preliminary goals can be set at certain values, but later analysis might lead to the conclusion that those values are unrealistic and, as a result, they will have to be reformulated. The draft FAO Guidelines for Land Use Planning calls this ‘two steps forward, one step back’ (FAO, 1989: 15). It distinguishes ten steps in the process of land use planning. These are refinements of the above three main phases of planned development of Van Dusseldorp (1980).

It is noteworthy that in the final version of the Guidelines for Land Use Planning (FAO, 1993a), and also in earlier drafts, planning is implicitly equated with planned development and not with plan preparation. This is one of the reasons that in the present study the term land use planning is not used for the kind of analyses done in the framework of the USTED (Uso Sostenible de Tierras En el Desarrollo)

57 Steps in land-use planning, as formulated in FAO (1993a: 12): 1. establish goals and terms of reference, 2. organise work, 3. analyse problems, 4. identify opportunities for change, 5. evaluate land suitability, 6. appraise alternatives, 7. choose the best option, 8. prepare land use plan, 9. implement the plan, and 10. monitor and revise the plan.
methodology (Chapters 6 & 7, while Section 4.5 provides a background), which has its roots in the LEFSA sequence (Fresco et al., 1992: 51-61; see Sections 4.3, 4.5 and 5.1 for more details). Instead, the term land use analysis is employed to emphasise that plan implementation is not a part of that methodology. Moreover, in the USTED methodology, taking decisions with regard to land use ('choose the best option'; step 7 of FAO, 1993a) are excluded too, as is elaboration of a 'final' plan ('prepare the land-use plan'; step 8 of FAO, 1993a). It confines itself to analysing possible land uses ('analyse problems', 'identify opportunities for change', 'evaluate land suitability', 'appraise alternatives'; steps 3 to 6 of FAO, 1993a)\(^{58}\). In a way, it resembles phases 1a, 1b and 3 of Van Dusseldorp, or the phases A to C of Tinbergen.

4.2.4 Comprehensive resource based regional agricultural planning

Regional agricultural planning can be executed in different ways. The one most related to land use planning is called 'comprehensive resource based regional agricultural planning' (Polman et al., 1982 and Moll & Schipper, 1994). Key adjectives are 'resource based' and 'comprehensive'.

Resource based refers to a form of planning which on the basis of inventoried resources tries to indicate what is possible in the future ('potentials') and what should be done to go from the present situation to the future one. Objectives have the function of steering future development in a certain direction.

Comprehensive means that all (sub-)sectors within the agricultural sector should be analysed, as well as all (sub-)regions. The philosophy behind this is that only by looking at all sub-sectors and all sub-regions is it possible to get a good overview of the possibilities and constraints, which in turn enables one to make good choices.

Comprehensive resource based planning focuses on all levels in the biophysical and socio-economic environment distinguished in Figure 4.1. Resource based planning starts with the determination of the production potentials on the basis of biophysical characteristics. In subsequent stages the objectives and constraints of farm households and the socio-economic environment are incorporated in the planning exercise to arrive at a set of action plans which are feasible and 'optimal' (or at least 'better than at present') under the stated possibilities, constraints and objectives. The

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\(^{58}\) See note 57; in the same vein, step 15 ('land use plan', see note 61 in Section 4.3) of the LEFSA sequence is not included in the USTED methodology.
idea behind this stepwise approach is that biophysical conditions can be determined objectively, and these conditions thus form the 'basic space' within which all planned agricultural activities must take place. The socio-economic environment is, at least in the long run, flexible, and through a stepwise incorporation of farmer's objectives and constraints, markets, institutions, funds, manpower, and the possibly conflicting objectives of groups in society, the 'basic space' can be reduced to a 'solution space'. Within the latter activities can be defined, which are feasible from a biophysical viewpoint, and which are acceptable to farmers and others involved in the agricultural sector under the present and expected future circumstances.

By way of illustration, a brief outline of the approach followed for regional agricultural planning in Sri Lanka is provided (Polman et al., 1982). The government selected the Matara District as a research area; thus a selection following an administrative division. To reduce the variability of natural circumstances within the district to acceptable proportions, the district was divided into three sub-regions which were considered homogeneous with regard to natural circumstances. The basis of this division of the district was a national system of agro-ecological zonation, which divides Sri Lanka in 24 zones, mainly according to rainfall regime and altitude (Joshua, 1987). The agricultural sector in Matara district was divided into seven sub-sectors59 according to the main crops: paddy, coconut, tea, rubber, cinnamon, other crops, and livestock; for each of these sub-sectors, land use types (LUTs) were specified. The actual and potential technologies of these LUTs were estimated on the basis of field data and results of research stations. The combination of land units with land use types and new, improved technologies resulted in a range of potential land use systems which could be supported by government interventions to induce their selection by farm households. Five types of farms were defined: from micro-holdings with less than one hectare to estates with hundreds of hectares. Markets for the output of the various LUTs were studied to determine the maximum feasible production for the district, and other institutions were reviewed to establish, among others, the government's implementation capacity. With this comprehensive framework of analysis, development strategies were determined for reaching objectives such as maximum regional agricultural income and maximum regional agricultural employment.

59 For a comprehensive methodology regarding the study of crop sub-sectors in a country see: de Graaff (1986) and Moll (1987).
In regional agricultural planning, the diagnosis of the present situation is followed by an analysis of the potentials and constraints for future development (in a methodological sense, the diagnosis is not necessarily completed before the planning proper starts). To determine these potentials and constraints, one approach is to follow a number of steps in an iterative process. These steps are called here a ‘pragmatic model for comprehensive resource based agricultural planning at the regional level’.

**A methodological approach: a ‘pragmatic model’**

Where formal mathematical programming techniques are not used (although these are not excluded), comprehensive resource based regional agricultural planning follows a pragmatic approach to an ‘optimal’ (or at least ‘better than at present’) utilisation of resources. The procedure of plan formulation is based on gradual exclusion of development possibilities starting from a complete inventory of technical potentials and then gradually imposing constraints going from the least removable external constraints to constraints which are easier to relax, i.e. of which the resolution is in the hands of the government itself. This procedure permits the formulation of realistic objectives and the analysis of constraints provides the basis for systematic identification of projects which are designed to remove the constraints.

Here, only the steps of the pragmatic model will be mentioned. For a full description of the steps the reader is referred to Appendix 2. The steps are as follows.

1) Formulation of a framework of national parameters, including objectives and constraints, guiding agricultural planning at regional level.

2) Inventory of land and water resources and estimation of technical possibilities for land use types (crops, livestock and other).

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The first description of this ‘pragmatic’ model can be found in ARTI/WAU (1981). See also Polman *et al.* (1982), Schipper (1983) and Moll & Schipper (1994). The ‘pragmatic’ approach is taken up by the research programme: Sustainable Land Use and Food Production in the Tropics (*Duurzaam Landgebruik en Voedselproductie in de Tropen*). This is a joint research programme of several departments of the Wageningen Agricultural University and research institutes of the Netherlands Ministry of Agriculture, Fishery and Nature Management (DLV, 1990). The present research is connected methodologically as well as institutionally to this ‘DLV’ programme.

For related approaches to regional (agricultural) planning, see: van Staveren & van Dusseldorp (1980) and Luning (1981).
3) Imposing supra-regional constraints on land use type development.
4) Economic feasibility of land use types.
5) Imposing constraints at farm level.
6) Identification and choosing of options, scenarios.
7) Identification of projects and programmes in a long-term perspective.
8) Reconnaissance of the future role of agriculture within the region.
9) The budget and the implementation capacity as a basis for final project selection.

Following the above steps would lead to the formulation of a plan for the development of the agricultural sector of a region. A major function of such a plan is the identification of project and programmes as instruments to implement the plan, as well as to make suggestions for possible policy changes.

4.2.5 Project and programme identification

Regional agricultural planning, and thus land use planning, should result in the identification of projects and/or programmes, with which the proposed changes in the use of land should be accomplished. Detailed formulation and execution of these projects and programmes, however, are not part of land use planning.

4.2.6 Policy implications

It is important for regional agricultural planning, and thus land use planning, to suggest changes in policies that do affect the use of land, if it is considered that such policy changes will be useful in bringing about a desired change in land use. However, the actual formulation of, and decisions with regard to policies require a higher level of planning.

After the general outline of regional agricultural planning, the remainder of this chapter will concentrate on land use planning as a particular form of regional agricultural planning. For this purpose, a recent approach to land use planning, the so-called LEFSA sequence will be discussed. The Land Evaluation and Farming Systems Analysis (LEFSA) sequence (Fresco et al., 1992), also forms a frame of reference for the approach to land use analysis as used in the present study.
4.3 Land evaluation and farming systems analysis for land use planning

The LEFSA sequence is an attempt to incorporate land evaluation (LE) and farming systems analysis (FSA) into a general approach to land use planning. It has been developed in a joint effort of the WAU and the ITC in Enschede. The LEFSA sequence couples the relative emphasis on soils and natural resources and the more quantified, formal matching procedures of land evaluation with the socio-economic focus, the diagnostic and on-farm testing approach of farming systems analysis.

The following quotation of Fresco, et al., (1992: 15-16) indicates the role of both land evaluation and farming systems analysis in land use planning:

"Land evaluation as well as farming systems analysis can be regarded as tools for land use planning. As ‘building blocks’ they form part of the procedure for land use planning. This is visualised in figure 1. Other building blocks are a ‘recognition of a need for change’, the ‘development objectives’, and an ‘overall socio-economic analysis’. Together these building blocks can be integrated into a land use plan. This is the essence of the ‘LEFSA’ sequence for the integration of land evaluation and farming systems analysis for land use planning presented in chapter 4.

Figure 1. A generalised procedure for land use planning

The main contributions of land evaluation to land use planning are related to three aspects.

1) Land evaluation looks at potentials for the use of land, for example potentials for the production of certain crops. It looks at future possibilities for the use of land, which is an important starting point for land use planning.
II) These potentials are based on an evaluation of physical and biological resources, especially land and water, and their possible uses, coupled to an evaluation of economic and social opportunities and constraints. It therefore intends to link biophysical disciplines to socio-economic ones. This gives land use planning a more thorough base.

III) Land evaluation has a strong geographical orientation. At a requested scale, it maps present land use, and the land units, their properties and their potentials for certain land use types. This provides land use planning with an overview of the whole region it is supposed to tackle.

The contributions of farming systems analysis to land use planning are twofold.

I) Farming systems analysis diagnoses the present situation with regard to farming and land use, by categorising, describing and analyzing farms and their components, like the household system, and the cropping and livestock systems; and by indicating and analyzing the linkages of farm systems with aspects of higher-level systems that impose constraints on farm level performance, e.g. input supply, credit, extension, and prices and marketing. When farming systems analysis and land evaluation are combined, land use types can be placed properly into farm systems.

II) Farming systems analysis gives insights in possible and necessary improvements in existing ways of farming. This can lead to recommendations with regard to the physical and institutional infrastructure, like a better input supply, but also to specific agricultural research programmes. These could be backed-up by a farming systems research programme, including on-farm experiments. As such a research programme can only be a long term exercise, it can not play a major role in land use planning in the short run; only in the long run, once results of farming systems research become available, these can be used in future cycles of land use planning."

The LEFSA sequence consists of 15 steps starting from the regional level down to the farm level and below. Reconnaissance land evaluation and rapid rural appraisal find their place at the regional level, while

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61 The 15 steps of the LEFSA sequence are presented below as outlined in Fresco et al. (1992: 51-61). However, although they form part of a ‘sequence’, they are not intended to be followed in strict order. Apart from iterative aspects, they are interconnected. Furthermore, side-steps and short-circuits are possible (see the flow charts in Fresco et al.), depending on the objectives and circumstances of a case. In ‘shorthand’, they can be named as follows: 1. objectives, 2. socio-economic factors, 3. agro-ecological zonation, 4. farming systems research, 5. first diagnosis of constraints in land use and farming, 6. broad selection of land use types, 7. reconnaissance land evaluation, 8. preliminary land use assessment, 9. analysis of farm systems and interactions of land use systems, 10. analysis of land use systems, 11. refined and detailed definition of land use systems, 12. (semi-) detailed land evaluation, 13. improving current farm systems / within farm ‘optimisation’, 14. improving land use at the (sub)regional level / (sub)regional ‘optimisation’, and 15. land use plan.
(semi-)detailed land evaluation and the diagnosis of farmer constraints take place at the lowest level. The sequence is iterative within and between levels of analysis so that at each level data can be cross-checked and referred to higher levels when inconsistencies occur.

At present, the LEFSA sequence is but a theoretical construct, based on a great deal of testing of most of its components, but the entire sequence as such has never been implemented. The underlying assumption is that the separate strengths of land evaluation and farming systems analysis can be integrated in such a way that the resulting whole is more than its parts. While there are strong reasons to believe that a combination of the approaches yields valuable additional information, this assumption needs empirical verification. This is an objective of the research programme in Costa Rica. However, this programme does

62 The main points and conclusions of Fresco et al. (1992: 2) can be summarised as follows:

"The current state-of-the-art in both land evaluation and farming systems analysis is critically reviewed and their relative strengths and weaknesses are discussed, with respect to the basic philosophy as well as their applications in practice. A comparison of both methodologies is hampered because the approaches originate from very different backgrounds, and have evolved in the mainstream of different scientific disciplines. While land evaluation is rooted in soil science, and in actual practice puts heavy emphasis on an agro-technical analysis, where economics is often involved only as an afterthought, farming systems analysis is concerned more with socio-economic constraints. The levels of analysis also differ to some extent, with land evaluation emphasizing the regional aspects and farming systems analysis concerning itself more with the farm level. However, these differences also provide a useful starting point for exploiting the complementarity between the two approaches. The scope for integration of land evaluation and farming systems analysis for land use planning is in three areas. First, through linking the respective units of analysis, land use types, and cropping and livestock systems, all being components of farms; second, through linking the levels of analysis (national, regional, farm and components of farms) to provide full cover of the entire hierarchy of systems; and third, through linking data via geo-referencing.

The development and application of an integrated land evaluation and farming systems analysis sequence, LEFSA, can improve land use planning by combining the strong points of both methods. This volume suggests procedures for such an approach, including the use of new computer-based techniques."

63 The programme forms part of a broader programme of research, training and development, the Atlantic Zone Programme (AZP), carried out since 1986 by the Wageningen Agricultural University (WAU), and its Costa Rican counterparts, the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE, the international agricultural research institute for Central America, Panamá and the Dominican Republic), and the Ministerio de Agricultura y Ganadería (MAG). Since 1991, the research has focused mainly on a methodology for land use analysis, aiming at a sustainable agriculture in

(continued...)
not pretend to be a complete application of the LEFSA sequences. Given
the aim of the programme and its limited means, it can only do research
on certain parts of the sequence 64.

With regard to the LEFSA sequence, two main questions are relevant
for the research programme. The first is how to integrate the
contributions of different disciplines, and at which levels and units of
analysis. The second relates to the relationships between levels and units
of analysis.

The first question is concerned with the problem of how to integrate
the contributions of different disciplines within the LEFSA sequence, and
at which levels and units of analysis this should take place. Three units of
analysis and three levels of analysis are considered. The first level of
analysis are single activities (or land use types), for example the
cultivation of maize or the fattening of cattle, both at the sub-regional
level as well as within a farm at the below-farm level. The second level
at which the integration of disciplines is to be accomplished, is the farm,
while the third level is the sub-region. The contributions of the different
disciplines at each level will be integrated through the use of models as
abstractions of reality. Models can be qualitative, but the emphasis is on
quantitative models. Such models force the disciplines to agree on precise
concepts, as well as to work towards a common product.

The second question in relation to the LEFSA sequence addresses the
nature of the relationships between the units of analysis at different
levels. This is connected to the differences between a micro and macro
analysis, both existing in ecology and economy, and has to do with
aggregation biases (e.g. the economy of the agricultural sector of a
region is different from the sum of the economic activities of all farms in
a region) and the incorporation of partial analyses in more general
analyses (Fresco et al., 1992: sections 4.3, 5.3.14B & 5.4). In the

\[ \text{\textsuperscript{63}(...continued)} \]

Central America. Recently, UNA (Universidad Nacional), Heredia joined the
programme.

\[ \text{\textsuperscript{64} The research programme consists of four sub-programmes:} \]
\[ \text{A actual and potential land use at the (sub-)regional level;} \]
\[ \text{B detailed land evaluation at the level of farms within the selected sub-region;} \]
\[ \text{C modelling land use at the farm and sub-regional level; and} \]
\[ \text{D integrating the results of thematic studies and verifying and improving the} \]
\[ \text{methodological approach and establishing alternative scenarios for sustainable land} \]
\[ \text{use.} \]

For a more detailed outline of these sub-programmes, and of the nine research projects,
see WCR (1990: 8-12 & appendix 3).
research programme, the relevant levels will be linked through multi-
level approaches. Although, the present research hopes to contribute to
the interdisciplinary research on both questions as formulated above, it
concentrates on the last question. Furthermore, it devotes attention to
questions with regard to the economic aspects of land evaluation itself.

As far as the present study is concerned, the design of a methodology
for land use planning, using the LEFSA sequence as a frame of
reference, is focused at the sub-regional level and the farm level. The
sub-region studied here is the Neguev settlement in the Atlantic Zone of
Costa Rica. Studies at farm level are also concentrated in that area.

4.4 Some suggestions for improving land evaluation

As mentioned above, land evaluation is a tool for land use planning. It is
worthwhile summarising here the critical review of land evaluation in
Chapter 2. In Section 2.3, land evaluation was criticised on several
points:

a) selection of land use types for evaluation;
b) definition and analysis of land use types in relation to farming systems
   in their regional setting;
c) definition of suitability levels; and
d) economic analysis of biophysical suitability classifications.

Some remarks will be made below on possible methodological
improvements concerning these points, except for the last point, as this
belongs more to the domain of land use analysis (Section 4.5).

Selection of land use types for evaluation

Several agro-ecological and economic criteria should be taken into
account. Examples of agro-ecological criteria are temperature, rainfall,
length of growing period and present land use. Economic criteria may
include comparative advantages of producing the possible land use type in
the (sub-)region versus producing it in other regions, price and marketing
prospects of each possible land use type, preliminary cost-benefit studies
per possible land use type, and whether the possible land use types would
fit into farming systems. These criteria will have to be made specific for
a particular study. The objective of this exercise is to establish
preliminary ‘attractiveness’ indicators of the different land use types
before a land evaluation is undertaken, in order to select land use types
for suitability assessment during the land evaluation.
In the case study, selection of land use types has been done in the above vein. However, most important was their convenience regarding the research programme, using in the first place the agronomic criterion that those land use types would be included which are representative for a particular type of crop: a cereal crop (maize), a root crop (cassava), a tree crop (palm heart), a crop belonging to the *Musa* genus (plantain), a fruit crop (pineapple), pastures, and trees for wood production. Limiting the study to just these representative land uses would reduce the amount of work for the research team, so that the research team could concentrate its efforts on the main task: the development of a methodology. In the second place, the selected land use types should be able to be spread in a convenient way over the relevant three main soil types: fertile well-drained, fertile poorly-drained and unfertile well-drained.

Whereas the land use types selected according to the first criterion are relevant and important land uses in the Neguev settlement, the case study area, and also in the Atlantic Zone of Costa Rica in general, certainly not all relevant crops at present are included: in particular bananas, but also ornamentals, papaya, soursop, macadamia, pumpkin, passion fruit, cacao, yams. Certain *a priori* reasoning played an important role in excluding those crops, for example, considerable capital requirements (bananas, ornamentals, soursop, macadamia), minimum area requirements (bananas), or recent experiences with regard to diseases (cacao, passion fruits), or with regard to marketing (e.g. yams).

Although sensible and practical, and justified because of the main research objective, the second criterion does involve *a priori* judgements regarding the suitability for the selected land use types for the three soil types. The resulting land use types and soil types to be considered are summarised in Table 4.1.
Table 4.1 Soil and land use type combinations included for consideration in the Neguev, Costa Rica case study

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Fertile well drained soil</th>
<th>Fertile poorly drained soil</th>
<th>Unfertile well drained soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Logged forest</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maize</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Palm heart</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pasture with cattle</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pineapple</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Plantain</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree plantation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Definition and analysis of land use types in relation to farming systems in their regional setting

As already mentioned in Section 2.3.2, note 11, Fresco et al. (1992: 164-165) define a land use type in a different way from FAO (1976: 83; see note 8). In an extended form they define it as "A specific kind of land use under stipulated biophysical and socio-economic conditions (current or future), seen as a subsystem of a farm. A land use type can be described according to its setting, technical specifications and requirements. There exists a similarity between the concept land use type and the concepts activity, cropping system and livestock system." A land use type is thus specified in terms of socio-economic and technical attributes, and of land use requirements. Land use requirements are biophysical conditions that affect yield and yield stability of the land use type (ecological requirements), management of the land use type (management requirements), and yield sustainability of the land use type (conservation requirements). For more information, see the different land evaluation guides, e.g. FAO (1983). The socio-economic and technical attributes refer to some general descriptors, the 'setting', and to more
specific agronomic and economic descriptors\(^6\). In this respect, the reader is referred back to Section 2.3.2 where land use types are discussed as sub-systems of farm systems, in accordance with the above cited definition.

In the present research, it is proposed to describe land use types only by cultivation practices, operations and input quantities, thus restricted to agronomic descriptors. In combination with prices, these descriptors allow the calculation of economic descriptors. For example, with the input quantities per ha and their prices, one can calculate the costs of inputs per ha. To make the definition of a land use type operational, cultivation/husbandry practices and input quantities of the agronomic attributes should be the same and constant per unit of measurement of the land use type over the suitability levels, e.g. per hectare or per animal. However, output per unit of measurement (yield) varies according to the suitability level of the land use type in relation to the land unit to which it is applied. In other words, if for a certain soil a certain crop is less suitable, implying a lower yield, it does not imply a different input use, for example of fertiliser.

Although this way of defining land use types might seem rather inflexible, it is the only possible way to compare the same land use type

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\(^6\) Fresco \textit{et al.} (1992: 200-201) propose the following:

1) setting
   * socio-economic
     - description of type of farming system(s)
     - size of farms
     - importance of land use type in each farming system
   * description of technology
   * agro-ecological zone
   * season

2) technical specification
   * agronomic
     - description of cultural practices
     - description of (labour) operations
     - quantitative inputs and outputs
   * economic
     - market orientation (percentage sold)
     - capital intensity (capital per hectare, and/or per unit of product)
     - labour intensity (labour per hectare, and/or per unit of product)
     - costs of inputs
     - costs of production
     - value of outputs
     - gross margin(s) per hectare, and/or per labour day
     - net benefits (annuity of .....).
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on different land units. In economic terms this can be expressed with the help of a physical production function. For a certain land use type (with a specified technology) the relation between the quality of the land and the quantity of the production per unit of land is defined, keeping all other factors constant (ceteris paribus). Figure 4.2 presents examples of such physical curves.

![Physical product of a specific land use type with varying quality of land](image)

Figure 4.2 Physical product of a specific land use type with varying quality of land

To create more flexibility, it is possible to define several 'sub' land use types for the same land use type according to different cultivation/husbandry practices and input levels\(^{66}\). To provide a simple example, maize could be grown with increasing amounts of fertiliser (to be specified in kg). Each method of maize cultivation will be distinguished as a separate land use type. In Figure 4.2 this could be expressed through different production functions, see lines aa', bb' and cc'.

At first sight, the above way of defining land use types might be strange to an economist. From a production economics point of view, it appears more appropriate to define for each land unit / land use type combination optimal input/output levels, in which the marginal costs equal the marginal benefits. However, it will be very difficult to do this prior to a land evaluation, as it is the land evaluation that is supposed to

\(^{66}\) Such 'sub' land use types could called 'production methods' or 'production techniques'; in Dutch: *productiewijzen* (Rabbinge, 1991). In the Costa Rica case study, land use types (abbreviated as LUTs) are defined more generally, for example a certain crop (e.g. maize), then combined with a soil type, which - for the purposes of the present study - can be considered to be same as a land unit (abbreviated as LU), to a land use system (abbreviated LUS), following Beek (1978) and Dent & Young (1981), see also FAO (1983 & 1993a) and Driessen & Konijn (1992). To distinguish different production methods or techniques within a land use system, the concept of *Land Use System & Technology* is introduced, abbreviated LUST, see Section 4.1 and note 55.
provide the necessary information. Furthermore, given the fluctuations of economic variables like prices, the specification of the land use types would change often, complicating the collaboration with biophysical disciplines.

The definition of land use types given here is comparable with a Leontief production function in which the input/output relations are assumed constant\(^67\). This also fits well into activity analysis, of which a linear programming model is an example. In such a model each land unit / land use type combination\(^68\) will be an activity with fixed input and output coefficients. By defining several activities, with different input and output coefficients (a ‘technology’), for each combination, the model provides ample room to choose an appropriate technology (Hazell & Norton, 1986: 32-42 & 156-159).

In the Costa Rica case study land use types and their technology are described in a very precise and detailed way (Jansen & Schipper, 1995), on the basis of which ‘summary’ input and output coefficient are calculated for use in a linear programming model. This is briefly explained in Section 4.5.2.1.

**Definition of suitability levels**

As explained in Section 2.3.3, in a land evaluation first a suitability classification is made on the basis of biophysical criteria. In Fresco *et al.* (1992: 95-96), the following approach is used in a case study of the Matara district, Sri Lanka. **Land use types are defined for a normative yield\(^69\), given a fixed input\(^70\) and management level, under the best**

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\(^67\) In a Leontief production function, different inputs \(X_1, X_2, \ldots, X_n\) are complementary, with the minimum input \(X_i\) defining the output (yield) \(Y\). Such a production function is comparable with a biophysical ‘Von Liebig’ or a ‘Linear Response and Plateau’ (LPR) function \(Y = \min (X_1, X_2, \ldots, X_n)\) for individual plants or crops on completely homogeneous plots. This can be consistent with differentiable production functions in which substitution between inputs is possible, because of the non-uniformity of plots (and farms), see Bereck & Helfand (1990).

\(^68\) In the terminology of land evaluation a ‘land use system’ (LUS); in the Costa Rica case study a LUST.

\(^69\) The normative yield differs from the potential yield, which reflects the genetic potential of a crop under those weather conditions, that determine the duration of the growth period and the length of the various phenological phases (temperature) and the rate of growth during that period (solar radiation), hence assuming optimum growing conditions throughout the growth periods (Fresco *et al*., 1992: 132). Normative yields (continued...
biophysical conditions in view of the sub-regional circumstances. Following the usual grading of suitabilities (e.g. FAO, 1976 & 1983), four levels are used (Table 4.2), based on the range of the yield in relation to the normative yield. For computational convenience a point estimate of the yields is also provided.

(...continued)

also differ from maximum station yields, because the circumstances at research stations, as well as their management practices most likely differ from the 'best biophysical conditions in view of the sub-regional circumstances'. Last but not least, the maximum station yields in their turn differ from the potential yields, because at research stations neither the local climate and soil constraints, nor the soil and water management practices, are as 'optimal' as defined for the potential yields (Fresco et al. (1992: 121). Studying the reasons for such differences in yields is often done under the heading of 'yield gap analysis' (e.g. Zandstra et al., 1981; World Bank, 1982; Fresco, 1984).

Using a normative yield in the definition of land use types assumes that farms when involved in a specific (thus with a specified technology, a LUST in the Costa Rica case study terminology) land use type (an 'activity') do so in a technically efficient way. In other words, a land use type is not produced inefficiently. Leibenstein's (1966) X-(in)efficiency does not exist within a land use type; however, farms could choose other (biophysically less efficient) land use types, for example by using less labour (in quantity: less hours; and/or in quality: working less intensive during the hours worked at the land use type). A corollary proposition is that within a land use type there is no allocative efficiency. Allocative efficiency can be reached in the choice between land use types at the farm level. For a discussion of (technical and allocative) efficiency, and the difficulties in estimating those from farm survey data, see Ellis (1993: 65-76).

Except for inputs which are directly proportional to the quantity harvested, e.g harvesting labour, transport costs. This is a sub category of the 'activity variable costs' (FAO, 1986: Volume I, 3 Data structure, 8-9), namely costs not only variable in relation to the size of the activity measured in hectares (or animals), but also variable in relation to the output per hectare (per animal).
Table 4.2  Suitability levels in biophysical land evaluation

<table>
<thead>
<tr>
<th>suitability level</th>
<th>range of yield relative to normative yield at a fixed input level (%)</th>
<th>point estimate of yield relative to normative yield at a fixed input level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'good' S1</td>
<td>76 - 100</td>
<td>0.9 * 100 = 90.0</td>
</tr>
<tr>
<td>'fair' S2</td>
<td>51 - 75</td>
<td>0.9 * 75 = 67.5</td>
</tr>
<tr>
<td>'poor' S3</td>
<td>26 - 50</td>
<td>0.9 * 50 = 45.0</td>
</tr>
<tr>
<td>'not' N</td>
<td>&lt; 26</td>
<td></td>
</tr>
</tbody>
</table>

Source: Fresco et al. (1992: 96).

The suitabilities could be defined briefly as follows (compare Visser & Dijkerman, 1988: 181-182).

**S1 Biophysically highly suitable, 'good'**
Land with no or slight limitations for the sustained application of a defined land use type; yields are between 76-100% of the normative yield.

**S2 Biophysically moderately suitable, 'fair'**
Land with moderate limitations for the sustained application of a defined land use type; yields are between 51-75% of the normative yield.

**S3 Biophysically poorly suitable, 'poor'**
Land with severe limitations for the sustained application of a defined land use type; yields are between 26-50% of the normative yields.

**N Biophysically not suitable, 'not'**
Land having limitations which precludes successful sustained application of a defined land use type; yields are between 0-25% of the normative yields.

Why only four levels of suitability as quality of land changes much more gradually if not continuously? In Figure 4.2 land quality increases in a continuous way along the x-axis. A continuously changing suitability would fit better with a production function approach to land evaluation. However, this would be neither realistic nor practical. In the first place, it would require much more data, which at present are not available and will not be available in the foreseeable future. In the second place, it is a question of whether the quality of land is changing in a continuous way or in more discrete steps. Obviously, not necessarily in four steps, but this is not a major point, suitabilities have also been defined in five, six
or more levels (e.g. FAO, 1993b). In the third place, the four levels could be interpreted as an approximation\textsuperscript{71} of a continuously changing quality of land. This is expressed in Figure 4.3.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure43.png}
\caption{Stepwise approximation of a continuous relation, for a specific land use type, between the quality of land units and the quantity of production per hectare of land (yield), keeping all other factors constant.}
\end{figure}

On the basis of these biophysical classifications, economic calculations are made. Using point estimates is done for ease of calculation. For related applications, see Fresco \textit{et al.} (1992: 95-99) and Erenstein & Schipper (1993: 19-21).

Of course, it is also possible to work with ranges. It would even be better to be able to use probability estimates, e.g. expected yield at each suitability level and variability. The percentages used in the above scheme are not a must, other ranges are also used, e.g. S1: 80-100\%, S2: 40-80\%, S3: 20-40\%, and N: 0-20\% (FAO, 1983: 61).

Another possibility - instead of point estimates of the yield of a land use type for each suitability level, without specifying the land unit - is to estimate the expected yield for each land use type / land unit combination, thus for each land use system. This would be preferable, but requires more and better information than is often at present available. In the Costa Rica case study the last approach is followed, using the LUST concept (Jansen & Schipper, 1995; see Section 4.5.2.1).

\textsuperscript{71} The relation appears to be linear, but this is not necessarily true, nor likely; the straight line in Figure 4.3 is only caused by the choice of equal segments on both axes. Hence, the length of the segments N, S\textsubscript{3}, S\textsubscript{2} and S\textsubscript{1} is not an indication of the quantity of land of a specific quality available.
It is important that much care should be taken in the estimation of normative yields, as this will be decisive for further calculations. Although much can be said about these estimations (van Diepen et al., 1990), for the time being and because it is outside the subject of the present research, it will be assumed that this will be taken care of by the biophysical disciplines involved in land evaluation. However, it is extremely important to compare the yields according to the above scheme with yields - and historical trends in these yields - as observed in the field (survey, and other sources of information), in order to be realistic. In this respect, 'yield gap analysis' (see note 69) could be of help.

4.5 Land use analysis

Land use planning has been defined in Section 2.1. Here some remarks will be made concerning the role of economic analysis within land use planning. First, however, attention is drawn to a change of terminology. From now on, the term land use analysis\textsuperscript{72} is preferred instead of land use planning. Land use planning has connotations of 'designing', 'making' and 'deciding' upon land use for the actual land users. However, in most situations land users themselves decide about the use of their land, not the land use planners nor decision makers at a policy level. Thus, land use planning can only analyse possible land uses - in the past, at present and in the future - and advise about the 'best' land use. Therefore, and because of arguments outlined in Section 4.2.3, the term 'analysis' is preferred over the term 'planning' (Schipper et al., 1995a). Nevertheless, on occasions the reader will find the term land use planning. In such cases please interpret planning in the sense of analysis.

In the LEFSA sequence for land use planning, Fresco et al. (1992: 51) distinguish five levels of analysis: national, regional, sub-regional, farm and activity/sub-system. At each level there are different tasks to perform; for an extended description, see Fresco et al. (1995: 51-61). The same volume contains an illustrative application of this sequence with regard to the Matara district in Sri Lanka. The 'pragmatic model' of Comprehensive Resource Based Regional Agricultural Planning distinguishes, albeit less explicitly, the same levels of analysis with comparable tasks, see Appendix 2. Different levels of analysis and the

\textsuperscript{72} Land use analysis as used here should not be confused with land use systems analysis (van Duivenbooden, 1995). Van Duivenbooden considers the latter a tool for land use planning.
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relations between those levels is a recurrent theme in (agricultural) planning (Tinbergen, 1967; Jansen, 1969; Goreux & Manne, 1973; González et al., 1977a & 1977b; Thio, 1979; van Dusseldorp, 1980; Luning, 1981; Norton & Solís, 1983).

In the present study, the economics of land use will be analysed at three levels only: land use system (crop/livestock system, activity), farm and (sub-)region. The national and regional level is excluded from detailed analysis for two major reasons. Concentrating on the mentioned levels allows for an intensive and detailed collaboration between the discipline of (agricultural) economics and two technical disciplines involved in the research programme: soil science and agronomy. In the methodology designed up to now, detailed aspects of the different soil types and their interactions with the performance of the land use types, including a precise description of the their technology, are taken into account. We believe that this is only possible at the mentioned levels of analysis, certainly when designing a methodology. Furthermore, abstracting from the national and the regional level of analysis justifies the assumption that important land use determining factors are exogenous to the model. This applies in particular to output, input and factor prices. In Section 5.3 and Chapter 6 more is said about these issues.

Models are constructed at each level incorporated in the analysis. At the land use system level, three data sets of input and output coefficients are important: coefficients based on farmers’ information, coefficients based on expert’s judgments, and coefficients derived from crop growth simulation models. These data sets are used for the construction of partial budgets. The economic consequences of the results of a land evaluation for different farming systems and for a regional economy can be assessed with the help of, in the first instance, linear programming models, and later multiple criteria analysis. Emphasis is put on the links between the farm and the regional level. To make those links operational, multi-level models could be constructed. In this respect, the way in which the farms in a region are grouped into different farming systems is important. An objective of the different models is to establish ‘land use capacity’ (Section 2.1) or ‘attractiveness’ indicators of different land use types, taking into account not only biophysical parameters (biophysical land evaluation), but also economic objectives and constraints, both at the farm and at the (sub-)regional level (economic land evaluation and land use analysis). Furthermore, sustainability oriented constraints are taken into account, not only at the land use system level, but also at the farm and sub-regional levels (sustainability analysis).

The land use analysis can be arranged in the following parts:
a) grouping of farms;
b) models per level of analysis
   - activity level  - input/output budgets  
   - - crop growth simulation / herd models
   - farm level  - models per relevant farm(ing) 
   - system, incorporating the activity  
   - models
   - (sub-)regional level  - models based on land use types, 
   - skipping the farm level;

   c) linking the farm and (sub-)regional level
   - (sub-)regional model including farm types
   - (sub-)regional model incorporating the ‘results’ of models of 
   - farm(ing) systems.

Each of these parts are elaborated below.

4.5.1 Grouping of farm systems

Considering the relation between the farm and sub-regional level, each 
farm in a sub-region is seen as a system (farm system) and is considered 
to be a subsystem of that sub-region. It would be ideal to analyse each 
farm system individually, but this is impossible, given the time and 
resources available. On the other hand, considering all farm systems as 
alike would be far too general an approach. A compromise between the 
two extremes will have to be sought by classifying individual farms into 
farm types. This could be considered one of the tasks of farming systems 
analysis (Fresco et al., 1992: 28).

One of the problems with grouping of farms is whether this can or 
should be done before or after a survey. Before a survey, or 
stratification, has the advantage that the variability of the main variables 
should be lower, but requires a priori information on all farms in a sub-
region before sampling of farms can be done. It is likely that the 
classification in that case will be based on simple straightforward criteria 
e.g. location (in a district or agro-ecological zone) or farm size. 
However, it is not certain at all that such a classification is sufficient for 
the grouping exercise. Therefore, it is most likely that the grouping of 
farms will (also) be done after a survey on the basis of the attributes of 
each farm as observed in the survey.

Day (1963) formulated three theoretical requirements of homogeneity 
if farms can be classified into groups, as formulated in Samad (1990: 
76):

1) each farm should have the same production possibilities, the same type 
of resources and constraints, and the same level of managerial ability;
2) individual farmers in a group should hold the same expectations about unit returns which are proportional to average returns; and
3) the constraints vector of each individual farm should be proportional to the aggregate farm.

Day calls these three requirements *technological homogeneity*, *pecuniary proportionality*, and *institutional proportionality*, respectively. These requirements are usually sufficient to guarantee unbiased aggregation. However, they are very demanding and are never fulfilled (Hazell & Norton, 1986: 146). This is elaborated in Section 5.1. Strict sufficiency, furthermore, requires that 'representative' farms are defined as 'average' farms and that none of the farm models are degenerate.

Difficulties with aggregating from a micro level to a macro level are not confined to a linear programming setting (Erenstein & Schipper, 1993: 4-5). Aggregation problems are well-known in econometrics (Theil, 1954 and van Daal & Merkies, 1984). The general conclusion is, to quote Oskam (1992, translated from Dutch): 'nearly nothing is permitted, and if something is permitted, it is not relevant in practice'. In the theory of production (Chambers, 1988, Gorman, 1968, and Muellbauer, 1975) a similar conclusion is reached: only under very strict conditions (e.g. a homothetic cost function) is aggregation permitted. In practice, such conditions are not realistic in agriculture, especially because of the (quasi-)fixed nature of some major inputs. However, although strictly speaking not permitted, much research in which those models or functions are used is going on. Often, a theory is developed at the micro level, regarding, for example, household models, production functions, profit or cost functions, while data are only available at a more aggregated level. For example, attempts have been made to estimate a production function with data from different farms, thereby violating basic assumptions (Ellis, 1993: 70-76), because this is the only way to test anything with the available data. In a similar vein, 'representative' farm models, stand-alone or as part of larger sector models, will continue to be used in programming types of models (Section 5.1).

In practice, the aggregation, and thus the grouping, criteria are brought down to some simple rules. Hazell & Norton (1986: 147) mention 1) similar proportions in resource endowments, 2) similar yields, and 3) similar technologies. The first rule is often approached through similar land-to-labour ratios, which means, if household sizes (or more precisely, household labour availability) are similar, grouping by farm size. However, this can only be correct if the land is also of similar quality. If not, some weighting of different parcels (land units) before summing the parcels per farm has to be done. Another approach is to take into account land-to-labour ratios for each land quality or soil type.
This has been done in the case study (Section 6.4; Schipper et al., 1995a). The second rule can be approached through grouping the farms according to, for example, agro-ecological zones and land units, and major differences such as irrigated versus non-irrigated land. The third rule can be approached by grouping of farms according to major cropping patterns and major differences in technology, e.g. large industrial export-oriented banana farms, versus smallholders producing bananas for the local market.

The above approach to grouping is also comparable to the classification of farms as attempted on the basis of data collected in the 1987 'general farm survey' in the areas Neguev, Río Jiménez and Cocori of the Atlantic Zone Programme (Section 6.2; Schipper, 1993: 24-32). This grouping was based on the location (area), farm size and relative importance of crops versus pastures, in that way taking into account rules (2), (1) and (3) respectively.

### 4.5.2 Models per level of analysis

For each of the three levels of analysis (land use system, farm and sub-region) models can be constructed. These are outlined below.

#### 4.5.2.1 Activity level models

Activity level models will be mainly of two types, input-output 'budgets', both in physical quantities as well as in monetary values, and crop growth simulation models. In the case of livestock, herd models will be important too. In the case study, the input-output budgets are based on farm survey data as well as on other sources, such as 'expert systems' evaluations and crop budgets of the BNCR (Banco Nacional de Costa Rica). The input-output budgets will be put together in collaboration with the agronomist. Where these budgets can also be based on a (semi-) qualitative land evaluation, the expert systems evaluations could be made with the help of ALES (Automated Land Evaluation System; Rossiter & van Wambeke, 1989). Examples of the application of ALES can be found in Van Lanen (1991). The other type of activity level models, the crop growth models, will be the responsibility of the agronomist or production ecology expert of a programme. The input and output coefficients derived from the activity level models are used for the preparation of crop budgets, while 'summary' coefficients are used in the farm and sub-regional level models (Jansen & Schipper, 1995).

Activity level models are prepared for the most relevant land use types in the pilot area of Costa Rica. Some are studied in more detail than
others. As explained in Section 4.4, the research programme, especially the crop growth modelling and expert systems part, concentrates on the following land use types: maize, cassava, plantain, pineapple, palm-heart, pastures, logged forest, and tree plantations. These land use types are studied in conjunction with their performance on three 'proto' soil types: i) young Holocene soils deposits, fertile with good drainage properties, ii) young Holocene soils deposits, fertile with poor drainage properties, and iii) old Pleistocene soil deposits with reduced fertility but good drainage properties. For all the relevant combinations of land units, land use types and technologies (LUSTs) detailed descriptions were made; in total 122. The descriptions follow the idea of an operation sequence (Stomph et al. 1994), in which all operations {tasks within an activity (land use system), involving at least a human, animal or machine power input; FAO (1986: Vol III, Appendix F)} 'from plot preparation to post-harvest operations' are characterised chronologically. Each operation, e.g. fertiliser application, weeding or harvesting, is specified through its date, human labour use, equipment (including animal or machine power) use, and material inputs or outputs (Jansen & Schipper, 1995).

For a case study, farm level data can be collected through surveys. The word survey should be interpreted in a wide sense. It refers to both participatory and non-participatory research on farm households. The main objective of the surveys is the establishment of relationships between land units, land use types and economic returns, within a farm system. Assessment of these relationships requires research into the following topics:
1) relationships between land units (parcels), land use types (crops and/or livestock) and yields. Parcels are classified according to soil type and measured. Yields are estimated on the basis of farmers' responses and measurements;
2) physical and economic input-output relations per land use type;
3) cultivation and husbandry methods by land use type;
4) availability and use of other factors, e.g. labour and capital;
5) economic returns ('incomes') obtained; and
6) objectives and strategies of farm households.
These data are necessary to assess the economic viability at farm level of different scenarios for sustained land use. For more information with regard to the survey in the case study area (stratification, type of surveys, selection of sample farms, results), see Appendix 4.
4.5.2.2 Farm level models

For the different farming systems in a sub-region, based on the grouping of similar farm systems, separate farm models could be constructed. These models will be, in the first instance, linear programming models. A basic reference for such models is Hazell & Norton (1986). Possible extensions might be quadratic models, incorporating risks; multi-period models, incorporating dynamic effects of investments in land improvements, capital goods, perennial crops and (agro-)forestry activities; and multiple goals, through multiple goal linear programming models.

The production activities in the models are the different land use systems as subsystems of the farming system, of which the coefficients can be derived from the activity level models. Other activities are related to off/non-farm work, renting of land and capital assets, the hiring of land, labour and capital, buying and selling activities, as well as household activities. The constraints consist mainly of farm level constraints: land units (parcels) of different qualities, (household) labour availability in different time periods, capital goods and inputs availability. Several objective functions are possible, also depending on the farming system under consideration. The nature of the objectives is one of the topics of a farm survey.

As usual with farm models, a number of parameters are determined outside the model. This applies especially to input and output prices. Nevertheless, the consequences of different prices for the farm models could be assessed.

In a case study, at a later stage, different versions of the farm models could be elaborated to incorporate the effects of regional (and national)

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73 In the case study, examples of farm level objectives could be the following:

small and medium farmers:
- to supply basic food requirements,
- to secure continuation of farming,
- to maximise income;

squatters (preciaristas):
- to supply basic food requirements,
- to earn an additional money income,
- to sell their occupied land, including the improvements;

large livestock farms (haciendas):
- to maximise income,
- to speculate on increasing land prices;

plantations:
- to maximise long-term profits.
constraints on the models. An example might be a market limitation for certain crops, e.g. palm heart, or the availability of labour in a region. Although unemployment is often a problem, this does not necessarily imply that there is an abundance of labour, either throughout the year or in certain periods, in an area. An indication of this is the often labour extensive (labour-days/ha) way of raising certain crops or livestock products.

The farm type models can be a part of models at the (sub-)regional level. Alternatively, the results of different versions of the farm models can be incorporated as activities in the multi-level regional model. In both ways the farm and (sub-)regional levels are linked (see Section 4.5.3). In the case study, the first approach is followed.

4.5.2.3 Sub-regional level models

The production activities in models at the (sub-)regional level could be the different land use systems, skipping the farming system. By skipping the farming system is meant that the farmer as a decision maker, with his own objectives, opportunities and constraints, is not taken into account. The (sub-)region is considered to be one farm with one decision maker. The coefficients for the model will also be derived from the activity level models. Other activities will be related to off/non-farm work, renting of land and capital assets, hiring of land, labour and capital, and buying and selling activities.

The constraints consist mainly of sub-regional constraints as land units of different qualities, (sub-)regional labour availability in different time periods, capital goods and inputs availability. Important constraints related to markets for agricultural products can be built into the model, by constraining the market and/or by building into the model demand functions in relation to product prices. As market limitations are important for production possibilities, the research programme is conducting a separate project on marketing issues (van Tilburg et al., 1995). These data are indispensable for the assessment of the economic viability of different scenarios for sustained land use. Other regional constraints might be related to the physical or institutional infrastructure. Furthermore, sustainability related constraints can be built into the
model. Also, the effects of several objective functions should be explored\textsuperscript{74}.

The different objectives have to be specified. This is not clear cut, especially for the 'sustainability' objectives. In the case study, this will have to be attempted in collaboration with the other disciplines in the research programme. Some sustainability objectives can be expressed as constraints. As the operationalisation of sustainable land use is one of the main subjects of the research programme, several working hypotheses are elaborated and their effects on the results of model assessed (Section 5.2.2 and Chapter 7). For an attempt to use minimum soil erosion as an objective, see Bok (1993).

The results of the (sub-)regional model (skipping farm level) will also be used as a benchmark for assessing the results of the models which attempt to link the farm level with the (sub-)regional level, either by incorporating farm types or by incorporating the results of farm level models into the (sub-)regional models. These models will be outlined in the next section.

Recent experiences with - farm level skipping - linear programming models in the context of land use planning are reported in Schipper (1990) and Erenstein & Schipper (1993). An earlier application of linear programming related to land evaluation can be found in Diltz (1980). For examples of multiple criteria analysis, especially (interactive) multiple goal linear programming models, see: de Wit et al. (1988), van Keulen & van de Ven (1988), Veeneklaas (1990a) and Veeneklaas et al. (1994). For a simple application with regard to land use in the Atlantic Zone of Costa Rica, see Bok (1993). Recently, a specific version of multi criteria analysis, 'compromise' programming (Romero & Rehman, 1989: 85-105), has been applied in Erenstein & Schipper (1993). The reader is referred to Sections 5.2.1 and 5.2.3 for more details on the models mentioned here.

\textsuperscript{74} In the case study, examples of regional objectives might be:
- to increase the incomes of the small and medium agricultural producers;
- to create sufficient employment for a growing population;
- to contribute to exports, both with regard to 'traditional' crops (banana, cacao), as well as 'new' crops as plantain, palm heart, macadamia, ornamentals, and roots and tubers;
- to maintain forest resources;
- to use soils in a sustainable way.
4.5.3 Linking the farm and (sub-)regional levels

The main idea behind linking the farm and (sub-)regional models is to give due account to objectives and constraints at both levels. At the farm level, the household objectives (Section 4.5.2.2) are to be maximised with the farm level constraints operative. Regional - policy - objectives do not play a role, nor are regional constraints binding, e.g. markets and hired labour availability. A further aspect is that prices of inputs, production factors and outputs are considered constant. They are not influenced by the demand for or supply by individual farms. On the other hand, at the regional level, household objectives are not necessarily relevant, nor is it possible to account for all specific farm constraints.

In theory, it might be possible to build a complete model incorporating both the micro objectives and constraints of each farm(ing) system, as well as the regional objectives and constraints. In a simplified case, such a model can be approached by introducing farm types into the overall model (Erenstein & Schipper, 1993; Schipper et al., 1995a). However, such a model can become very complicated and it may not always be wise to attempt. Also, it is part of reality that not all economic decisions are taken simultaneously with perfect knowledge of both decision levels. Micro level decisions are taken without ‘knowledge’ of the decisions made at the regional level, while the same applies to the regional level. Regional level decisions are taken without ‘knowledge’ of the decisions by the very many individual farm households (Section 5.1).

Two approaches are possible. One possibility is to incorporate models of farm types into a (sub-)regional model. Their matrices, containing farm level activities and constraints, become integral parts of the overall model. As a consequence, the overall model, and the farm models as parts of the overall model, have one common objective, for example, the sum of the incomes of the farm type models. Another possibility is to incorporate the results of different versions of farm type models into a (sub-)regional model. Each result can be represented by a column vector. In this case the objectives for the farm type models and for the (sub-)regional model are not necessarily the same.

In the case study most attention is paid to the first possibility. The reader is referred to Chapters 5 and 6 for an extensive treatment, including further additions which could be built into the model such as downward-sloping demand functions (Hazell & Norton, 1986: 164-215) and the element of risk (Hazell & Norton, 1986: 76-111 & 216-238). Furthermore, the effects of different objective functions, reflecting different regional objectives with regard to income, employment and sustainability aspects, could be assessed, giving the models the character
of multi-criteria models. For a recent publication on such models, see Romero & Rehman (1989), who deal extensively with different methods of 'multiple criteria analysis for agricultural decisions' (Section 5.2.3).

The second approach can be envisaged as follows. Different versions are made of each farming system model, each reflecting the effects of different (values of) regional constraints (or objectives) on these farm models. The results of those different versions, in terms of the regional objectives and constraints, will be activities of the regional model. See Hazell & Norton (1986: 320-323) for an outline of such multi-level procedures, plus further references.

This approach has been tried in a hypothetical case study based on data of the Leziria Grande project, a land evaluation study in Portugal (Samana, 1979; Beek et al., 1980; Socio-economic Working Group/DGHEA/ILRI, 1984). For a part of the area of the project, a linear programming model was set up as an exercise for a course in the application of 'mathematical programming in planning' (Jansen & Schipper, 1985).

A first assumption for setting-up the linear programming model was that the part of the Leziria Grande project area (in the terminology of the present research a sub-region) could be considered to be one farm, a state farm, managed by one decision maker. The model was to maximise the financial surplus generated by crop activities (land use types), given limited availability of two types of land (land units), rotation requirements, and labour and irrigation water restrictions.

A second assumption was that in the 'sub-region' (on the land of the state farm) vegetable farms were to be established. The crop activities within a farm have a fixed (per hectare) demand for water as well as for hired labour. Of course, these activities differ in their demand for water and hired labour. The optimal solution of such a farm generates a certain demand for irrigation water and hired labour. If one, or few, such farms were created, there would be no problem. However, the establishment of many such farms would generate an aggregated demand for labour and water which the region could not supply. This would possibly generate a regional solution which would not satisfy the regional policy of accommodating as many vegetable farms as possible, given a certain income goal of the vegetable farms. To accommodate a sufficient number of farms, 12 different versions of the farms were modelled, each with different availability of land, labour and water (related to the institutional proportionality of Day (1963); Sections 4.5.1 and 5.1). The results of those versions were activities in the regional model. The optimal solution of the regional model determined the number and types of vegetable farms (Jansen & Schipper, 1985). Of course, this was dependent on the
area of the sub-region available for the farms, which is a regional level policy decision. As a follow-up of the present model for the case study area in Costa Rica (Chapter 6), an analogous model could be constructed. For background information on similar approaches to linking programming models at different levels, see Goreux & Manne (1973) and Norton & Solís (1983).
5 A LINEAR PROGRAMMING APPROACH TO LAND USE ANALYSIS

5.1 Levels of analysis and aggregation issues

Land use planning is directed towards the 'best' use of land, in view of accepted objectives, and environmental and societal opportunities and constraints. Looking for optimal land use is akin to the principle of linear programming or other optimisation models, in which an objective function is maximised by selecting from alternative activities (opportunities), subject to constraints. Linear programming can thus be of help in the search for the 'best' land use. As explained before, the subject of the present study is not so much planning, but analysis of possible land use. The definition of land use planning also includes the time path of interventions in order to progress from the present situation to a future one, in other words, how to change land use. Linear programming can be of help to indicate future land use by searching for 'best' land uses. However, it is not a suitable technique for indicating the right interventions. This will be discussed in more detail in Chapter 8.

An important aspect of the proposed methodology for land use analysis is the differentiation between levels of analysis: LUST (activity), farm, sub-region, region and nation, comparable to those in the LEFSA sequence. Levels of analysis are related to levels of decision making.

Addressing several levels of analysis at the same time gives rise to aggregation issues. In the context of land use analysis three points are at stake (Erenstein & Schipper, 1993). 1) The use of land is often considered without 'knowing' the behaviour of the farm households responsible for the actual use of land. 2) The aggregation bias, as individual farmers have resources at their disposal in different proportions from the aggregated resources of a region. 3) Variables that are exogenous at the micro level become endogenous at higher levels. For example, individual farmers may not perceive markets as a constraining factor, but if most farmers in an area act in the same way price adjustments in input and output markets may or will occur. The same applies to factor markets. An individual farmer, being a marginal actor, may hire as much labour as he likes, but if all farmers do the same, they

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will come up against a regional labour constraint. These problems are well known from efforts to build (linear programming) models at a national or regional level.

**Aggregate decision problems** involve choices on at least two levels (Erenstein & Schipper, 1993: 5). At the macro level, a policy maker tries to decide how best to allocate funds in the face of:
- more than one objective;
- uncertainty about what the allocational consequences, for example with regard to land use, will be.

At the micro level, farmers have their own decision problems. They have to decide how best to respond to the new policy environment, given their own objectives and limitations of action. However, it is not known beforehand at the macro level what this response at the micro level will be. It is this *'not knowing'* that causes the uncertainty at the macro level about the allocational consequences. In order to solve the macro or policy problem, the uncertainty surrounding micro responses has to be reduced. In other words, some means of simulating the probable response of farmers is required before a policy decision is taken. In this context, multi-level models, or, where only two levels of decision making are involved, two-level models, have been proposed. Hazell & Norton (1986: 141-143), following Candler & Norton (1977) as well as Candler *et al.* (1981), outline the principles of such a model, involving - interdependent - constrained optimisation at both levels. However, such models are not directly solvable, because they do not have a convex feasible set, although local optima might be found[^76].

In practice, efforts are concentrated on simulating producer decisions by building a model that reflects their constraints, opportunities and objectives. This model is then solved under varying assumptions about the policy environment affecting producers. Agricultural producers, however, differ widely in their resource endowments and economic opportunities. Therefore, an adequate investigation of producer response to policy changes requires models of representative farms (Sections 4.5.3 and 6.4). The simulation of the probable response of farmers is further complicated by the fact that farmers usually have a number of objectives and preferences. This precludes the establishment of profitability, for example, as a sole choice criterion (Diltz, 1980: 7). Thus, an imaginary farmer may strive to achieve the following objectives (in order of importance):

1) provide subsistence requirements of his family today (either by on- 
farm production or by purchase); 
2) provide funds for emergency or short-term educational expenses of his family; 
3) maximize the long-term profitability of his farm; and 
4) sustained use of (natural) resources.

But no matter how good the simulation of probable response of farmers is, in the end it is the farmer who decides on, and is responsible for, the actual use of the land. Even in highly centralised economies there are limits to the extent that governments can dictate cropping patterns and other production decisions, and this is much less so in market-oriented economies. Therefore, finding the ‘optimal’ cropping patterns from a policy viewpoint may not be very useful, unless ways are also found to induce farmers to adopt those cropping patterns.

At sector-level an aggregation bias arises because farms are not similar. Ideally, for the aggregation to be correct, a model should be constructed for every individual farm. These individual models could then be linked together to form a sector model. Since this is unfeasible in practice, two approaches may be considered.

1) Aggregate regional model: this involves aggregating the resources of a region and modelling these aggregated variables as if they formed a single large farm.

2) Representative farms model: this involves classification of the universe of farms into a smaller number of homogeneous groups. A model is constructed for a ‘representative’ farm from each group. These farm models are then aggregated in a sector model using the number of farms in each group as weights. To limit aggregation bias, this procedure places a high demand on the proper definition of the representative farms and the weighting procedures.

Both approaches overstate resource mobility by enabling farms to combine resources in proportions that are not available to them individually. Both approaches also carry the implicit assumption that all farms have equal access to the same technologies of production. Therefore, in general, the value of the objective function (in a maximisation problem) of an aggregated model is higher than that of the objective function of a disaggregated one (Hazell & Norton, 1986: 145; Erenstein & Schipper, 1993: 3). In order to minimise aggregation bias...

However, the bias might be small, in particular if farm types have different resource proportions, but the same production possibilities; the more so if one of the (continued...)
bias, farms are to be classified into groups or regions defined according to requirements of homogeneity.

Notwithstanding the problems related to the aggregation bias, there are many studies in which aggregate models are used to simulate likely behaviour at the sector level, ignoring important differences at the micro level (e.g. Bakker, 1986a and Vreke, 1990), or to make a reconnaissance of production possibilities (e.g. Scheele, 1992). In fact, the early linear programming models for the agricultural sector were aggregated models (e.g. Heady & Egbert, 1964). In the transition from farm-level to regional or sector-level analysis there is an aggregation problem with respect to the nature of the variables. Variables that are exogenous at the micro level may be endogenous at the meso or macro level. Product prices, for instance, are normally considered as given for individual producers, but may be variable for a region as a whole. The entire service sector is normally considered as given for individual producers, but is a variable for a region as a whole. It is at the regional or higher level that resources have to be devoted to the service sector. Examples are the extension service and formal credit facilities.

In the remainder of this chapter the use of linear programming models as a tool for land use analysis is elaborated. After stating the principles of agricultural sector models in Section 5.2.1, including a comparison of three land use models with regard to those principles, the incorporation of sustainability parameters in linear programming models is examined in Section 5.2.2. Section 5.2.3 presents a short discussion of single versus multiple goals models, while in Section 5.2.4 the use of linear programming models in economic analyses is addressed. Finally, in Section 5.3, the use of linear programming models in land use analysis is outlined.

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77(...)continued

resources (e.g. labour) can be 'exchanged' between farm types (Erenstein & Schipper, 1993: 71-72 & 89-90); see also Bell et al. (1982: 42-43).

78 For a general review of agricultural sector programming models, see Norton & Schiefer (1980).
5.2 Linear programming as a tool for land use analysis

5.2.1 Agricultural sector models

Linear programming models used as a tool for land use analysis at the sub-regional level can be viewed as (mini) agricultural sector models. Potentially they are useful for policy formulation with regard to land use and related (sustainable) agricultural development (Schipper et al., 1995a). A sector model contains, implicitly or explicitly, a number of elements (Hazell & Norton, 1986: 136-137):

1) a description of producer’s economic behaviour;
2) a description of currently available and potential production functions, or technology sets, now and/or in the future;
3) a definition of the resource endowments held by each group of producers;
4) a specification of the factor and product markets; and
5) a specification of the policy environment.

Sector models differ in their degree of comprehensiveness and detail. Most often they are comprehensive with regard to all sources of supply and demand of the products within the agricultural sector of a region, but not with regard to the factors of production. Some factors are sector-specific, for example land, while others can be employed in various sectors, especially labour and capital. Examples of agricultural sector models for Mexico can be found in Goreux & Manne (1973) and Norton & Solís (1983)79. A similar application of linear programming to the agricultural sector of Costa Rica can be found in Celís (1989).

It is useful to review a number of land use analysis models with regard to the mentioned elements. Three studies are compared, a linear programming model in the context of land suitability evaluation in Sierra Leone (Diltz, 1980), a multiple goal linear programming model for a reconnaissance study of agricultural potentials in the Fifth Region of Mali (Veeneklaas, 1990a), and a linear programming model of possible land

79 Comparable (regional) sector models have been constructed for Colombia (Daines, 1982), Central America (Cappi et al., 1982), Egypt (Kutcher, 1980; Norton, 1982; Hazell et al., 1995), the Muda irrigation project area in Malaysia (Bell et al., 1982), Northeast Brazil (Kutcher & Scandizzo, 1981), Pakistan’s Punjab (World Bank, 1977), Pakistan’s Indus Basin (Duloy & O’Mara, 1984; Ahmed & Kutcher, 1992), Philippines’ agricultural sector (Kunkel et al., 1978), Thailand’s agricultural sector (Stoecker et al., 1982), Thailand’s Central Region (Rijk, 1989), Tunisia (Condos & Cappi, 1982) and Turkey (Le-Si et al., 1982; Norton & Gencağa, 1985).
use in the Matara district of Sri Lanka, also based on linear programming models (Erenstein & Schipper, 1993).

The first model is one of the earlier applications of linear programming in land suitability evaluation. It concerns a small model of two villages in the Makoni catchment area in Sierra Leone. Total area is 808 ha with a farm population of 216 persons. The villages contain 45 possible land units {9 land facets with 5 accessibility classes (distance from village)} and four labour peak constraints. Five land use types (LUTs) {single or double crop paddy, two rotations (maize, cassava, groundnut; maize, cassava, soya bean) and coffee} are evaluated. Each LUT has a suitability (four grades $S_1$, $S_2$, $S_3$, N) with regard to each land unit, specified in terms of the physical yield (kg/ha), calculated relative to a normative yield on the best land\textsuperscript{80}. Each of the LUTs requires land, and labour in four periods. For each the Net Present Value (NPV) is calculated over a 30 year period at a 16% discount rate. A minimum subsistence consumption of rice is specified. However, the village can choose between producing its own rice or buying it (at a higher price than the selling price at which the production is valued).

The second model concerns the Fifth Region in Mali (total area 8,980,000 ha, 1987 population 1,370,000 persons; Cissé & Gosseye, 1990), sub-divided into 11 sub-regions. The model is representative of a series of (interactive) multiple goal linear programming models directed at exploratory surveys of potential agricultural land use. These studies are done at various levels\textsuperscript{81}. In the model no farm types are considered, so each sub-region can be seen as one farm, sometimes called a super farm.

\textsuperscript{80} $S_1$-land 100% of normative yield; $S_2$-land 75%; $S_3$-land 50%; and N-land 25%.

\textsuperscript{81} Examples of such studies are: supranational level (WRR, 1992), regional level (Ayyad & van Keulen, 1987; de Wit et al., 1988; Veeneklaas, 1990a; Shakya & Leuschner, 1990; Schans, 1991; McGregor & Dent, 1993; Zekri & Albisu, 1993; Rosato & Stellin, 1993; Manos & Gavezos, 1995), or farm level (Piech & Rehman, 1993; Maino, Berdegue & Rivas, 1993; Stroosnijder et al. 1994; van Rheenen, 1995; van de Ven, 1996).

At the national/sectoral level, no representative examples of a (interactive) multiple goal linear programming model could be found, though in Bakker (1986a & 1986b) a linear programming model of the Dutch agricultural sector is discussed that could be considered a predecessor of such models. The model of Bakker is solved for four different versions of autarchy objectives (1986b), as well as for a profit maximisation objective (1986a). In a similar vein, a linear programming model of the Colombian agricultural sector (Daines, 1982), is maximised, subsequently, according to three objectives: employment, production and private profits; thereafter, trade-offs between these objectives are studied.
No labour migration between the sub-regions is possible, while emigration from the Fifth Region is restricted. Crop land use types (millet, fonio, sorghum, groundnut, cowpea, onion, vegetables, fodder crops, and rice) with different technologies ('intensification levels') are evaluated for 12 land units (soil types) in each sub-region (thus comparable to the LUST concept), taking into account a minimum distance (6 km) to a water point. Similarly, a pasture land use type is considered for four soil types, taking into account two distance circles around a water point (6 and 15 km). The yields (main product and by-product for livestock) of each LUST are set for the linear programming model on the basis of literature, field and/or experimental data, or simulation models (van Duivenbooden et al., 1991). Furthermore, the yields depend on whether the amount of rainfall conforms to a dry or normal year. Each LUST requires monetary inputs, traction (oxen), nutrients (manure and/or fertilisers) and labour, specified for six periods during a year. All LUSTs are defined in such a way that no soil nutrient depletion occurs. Pasture produces forage. The quantity produced depends on distance to a water point and season (dry or wet). Livestock (cattle, sheep, goats, donkeys, camels) activities require forage, labour and money. Livestock produces meat, manure and/or oxen traction, depending on the type of livestock. Lastly, the model has a fishery activity.

Constraints in the Mali model are formulated for land (per soil type per sub-region, considering minimum distances to water points), labour per sub-region in six periods, manure and oxen traction, and forage. Additional constraints operate for fish catch, donkeys and camels. Being a multiple goal model, it is optimised, in different runs, with respect to a number of goals. Depending on the run, a goal can be expressed in the objective function as a 'goal variable'\(^{82}\) and/or in a constraint. In the latter case these goals are called 'restricted variables'\(^{83}\).

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\(^{82}\) The goal variables are: total millet/sorghum/fonio production, total rice production, total marketable crop production, total monetary revenue, total employment, total meat production, total number of animals, total monetary inputs of all agricultural and fishery activities, total grain deficit in a dry year.

\(^{83}\) The restricted variables are: total beef production, total milk production, total monetary input in crop activities, total monetary input in livestock activities, total millet/sorghum/fonio production in a dry year, total rice production in a dry year, total crop production in a dry year, sum of sub-regional grain deficits in a dry year, total number of animals at risks in a dry year, labour emigration out of the Fifth Region.
The Mali model results in different land use patterns according to the different goals. Trade-offs between goals can be traced. Interaction with policy makers is therefore desirable, if not a prerequisite for a successful analysis. To ease the interaction with policy-makers scenarios can be constructed. Veeneklaas et al. (1994) compare two scenarios, the R-scenario, indicating a high-revenue, but risky development, and the S-scenario, indicating a self-sufficiency, safety-first, development. In subsequent steps, goals are maximised (or minimised) under different, increasingly restrictive bounds of the 'restricted variables'.

The third model analyses possible land use options in the Matara district, Sri Lanka (total district area 129,000 ha; 1981 population 643,000 persons), for the year 2000 with 1980 as a base year. Eight perennial (vegetatively propagated tea, seedling tea, rubber, coconut, coconut with buffalo, cinnamon, citronella, home garden) and six annual (paddy, six variants: irrigated or rainfed; hand labour, animal power or tractor) land use types are evaluated for 79 land units spread over three sub-regions. Each LUT has a specific suitability (four classes, S₁, S₂, S₃, N) for each land unit. Physical yields are determined on the basis of this suitability relative to a normative yield\(^{84}\). All LUTs require land, labour in each month, fertilizer, and other inputs; additionally, irrigated paddy requires irrigable land, while paddy using animal traction requires buffaloes. Per sub-region, constraints are placed on land units, labour per month (nevertheless, working in other sub-regions is allowed for, albeit at a certain cost), irrigable area and buffalo availability. Furthermore, demand for some export products (tea and cinnamon) is restricted in view of the fact that demand is inelastic and a large proportion of the world market is supplied by Sri Lanka. Similarly, the domestic demand for curd is limited. In the base version of the model, the three sub-regions are considered to be super farms. In an extended version, five farm types are distinguished in one of the sub-regions. For each of these farm types specific constraints for land units and labour are formulated. In another version of the base model, the trade-offs between three objectives (national economic net benefits, private financial net benefits and employment) are analysed. In addition, ‘compromise’ programming solutions are discussed.

In Sri Lanka, government policies with regard to export taxes and fertiliser subsidies introduce distortions in farm-gate prices. Furthermore, as unemployment is large in the Matara district, it could well be that the market wage does not represent the opportunity costs of labour. In order

\(^{84}\) S₁: 90% of normative yield, S₂: 67.5%, S₃: 45%, N: 0%.
to account for these market imperfections, three types of objectives are formulated, each referring to a balance of benefits and cost, but valued at different prices: 1) accounting prices for products and fertiliser, and a zero shadow wage rate; 2) the same, but with a market wage rate; and 3) actual market prices. The third objective is most representative of the producer's economic behaviour, while the first two represent situations in the absence of an export tax and fertiliser subsidy.

A comparison between the three studies is provided in Table 5.1. It should be realised that the three examples are cases at differing scales. The Makoni catchment area in Sierra Leone comprises 808 ha with a population density of about 27 persons per km$^2$, the Fifth Region in Mali has 8,980,000 ha with a density of 15 persons per km$^2$, while the Matara district in Sri Lanka consists of 129,000 ha with a population density of 498 person per km$^2$. Nevertheless, comparing the three examples of land use programming models provides some perspective for the Costa Rica case in the present study.

Considering producer's economic behaviour, some measure of economic calculation is taken into account in both the Sierra Leone case and the Sri Lanka case, but not in the Mali case. In the latter case, producer behaviour is not studied, and agricultural potentials are only considered from different policy perspectives. However, the Mali case does take into account minimum production requirements with regard to subsistence needs, including a 'dry' year basic grain requirement. A minimum consumption requirement is also included in the Sierra Leone case.

With respect to actual and potential production systems, the Sierra Leone case concentrates on actual systems, while the Sri Lanka case includes only the better actual systems; both hardly differentiate between technologies. In the Mali case the emphasis is on potential systems without a positive soil nutrient depletion; most systems can be produced with different technologies.

Considering the resource endowments held by each group of producers, the three studies have land and labour constraints. Land constraints are specified per land unit, each with different land use capacities. Labour is specified per period to account for different labour demands throughout the year. Additionally, the Mali study includes constraints related to the interaction of crops and livestock (fodder, oxen traction, manure), while in the Sri Lanka case draft power and the irrigable area are restricted. The above constraints are specified per sub-region in both the Mali and Sri Lanka cases (Makoni in Sierra Leone is a sub-region), not per farm type, except in the 'extended' version of the Sri Lanka case where farm types are distinguished in one of the sub-regions.
Table 5.1  Comparison of three models concerning land use

<table>
<thead>
<tr>
<th>Distinguishing element (description/specification)</th>
<th>Model</th>
<th>Model</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Land suitability evaluation, Sierra Leone (Diltz, 1980)</td>
<td>Land use optimisation in Fifth Region of Mali (Veeneklaas, 1990)</td>
<td>Land use potentials in Matara district, Sri Lanka (Erenstein &amp; Schipper, 1993)</td>
</tr>
<tr>
<td>1) producer's economic behaviour</td>
<td>maximise farm gross margin (NPV; 30 years, 16%) at farm-gate prices of two villages within a watershed; minimum subsistence rice consumption</td>
<td>at policy level only, multiple goals to evaluate potential production and trade-offs between 11 goals: physical production, monetary income &amp; employment; minimum dry year subsistence needs</td>
<td>maximise on-farm income at farm-gate prices; based on LUSs incomes (value added or surplus) calculated as annuities of NPV over life-span of LUSs at 10%</td>
</tr>
<tr>
<td>2) actual and potential production functions (technology sets)</td>
<td>LUSs (30 year rotations on land facets) with fixed input and output quantities per ha</td>
<td>annual LUSTs with fixed input and output quantities per ha, excluding nutrient depletion</td>
<td>perennial &amp; annual LUSs with fixed input and output quantities per ha</td>
</tr>
<tr>
<td>3) resource endowments held by each producer group</td>
<td>land units (land facets &amp; accessibility), peak labour; per village</td>
<td>arable &amp; pasture land units, labour per period (6), oxen traction, manure, forage, subsistence needs; per sub-region</td>
<td>land units, labour per month, draft power and irrigable area; per sub-region and per farm type</td>
</tr>
<tr>
<td>4) factor and product markets</td>
<td>fixed prices for input &amp; outputs, demand is not limited; labour can be hired</td>
<td>fixed prices for inputs &amp; outputs, demand is not limited; no labour migration between sub-regions; limited emigration</td>
<td>fixed prices for inputs &amp; outputs; demand limits for tea, cinnamon &amp; curd; labour migration between sub-regions</td>
</tr>
<tr>
<td>5) policy environment</td>
<td>not specified, except for a fertiliser subsidy</td>
<td>specified per scenario reflected in goals to be maximised and/or restrictions on goals</td>
<td>export taxes (tea, rubber, coconut, cinnamon) and input subsidies (fertiliser)</td>
</tr>
</tbody>
</table>
Regarding product markets, in all three cases, demand for crop and livestock products is not limited, except for tea, cinnamon and curd in the Sri Lanka case. Products are valued at a fixed price. No sensitivity analysis is affected with regard to the product prices. With respect to factor markets, in all the studies land cannot be rented in or out. In the Sierra Leone case labour availability is limited to labour in the catchment area plus 10%, while in the Mali case labour is limited to the sub-regional level, without the possibility of labour exchange between sub-regions. Labour is not valued, in other words it does not receive a wage. However, labour can migrate to a limited extent outside the region, in which case it receives a remuneration. In the Sri Lanka case labour is restricted at the sub-regional or farm level, depending on the version, while labour in one sub-region (of one farm type) can work in other sub-regions (on other farm types). If so, working in another sub-region involves a ‘travel’ (or transaction) cost.

The policy environment is not specified in the Sierra Leone case, except for a subsidy on fertiliser. Farm-gate prices of products are assumed to be international prices corrected for transport and other costs. As remarked earlier, in the Mali case policy options are maximised (or minimised) without taking into account the producer’s economic behaviour. Therefore, it is doubtful whether one can speak of a policy environment. Rather, the exercise creates a ‘solution space’ containing potential land uses following the pursuit of different policy desires. It does no more than make a survey of such a solution space. This is in itself useful for creating awareness at the policy level of different goals and their consequences in terms of land use and their effects on other (competing) goals, but it is not a real policy study. In the Sri Lanka case the policy environment is specified through export taxes for the main products and a fertiliser subsidy. By comparing solutions with or without taxes and subsidies, the partial effects of these taxes and subsidies can be studied.

The above comparison between three land use studies with regard to the five distinguishing elements of an agricultural sector model, provides a perspective for the model of the Costa Rica case in this study. This

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85 Of course, the Mali study was never intended to be a policy study; it aimed at being not more than a reconnaissance. For that matter, one can have doubts whether the Sierra Leone or Sri Lanka cases can be considered to be suitable for studying policy options. On the one hand, much depends on the realism of the assumed objectives, options and constraints, as well as the coefficients. On the other hand, a linear programming model is not a very appropriate tool to simulate real world behaviour of farm households.
case, to be introduced in Chapter 6, concerns the Neguev settlement area in the Atlantic Zone of Costa Rica. A first observation relates to the scale of the model. The Neguev region has a gross area of 5,340 ha, with a farm population of about 1,535 persons, implying a population density of 29 persons per km². Thus the area is about five times the size of the Makoni area in Sierra Leone, with a somewhat higher population density. However, the area is much smaller than the areas in the Mali case or in the Sri Lanka case, while the population density is double that of the Fifth Region in Mali, but only 6% of the density in Matara district in Sri Lanka. Moreover, in terms of the total size of the Atlantic Zone of Costa Rica, about 900,000 ha, the Neguev area is small.

Applying the elements of Hazell & Norton to the sub-regional model of the Neguev case presented in the next chapter, the following remarks can be made. 1) In the model the behaviour of the producers is described by assuming that each farm type maximises its returns to land, own capital and management of the farm, in conjunction with possible off-farm labour income. It reflects elements of economic calculation on the part of farm households, whose decision making resembles constrained optimisation. A careful and precise description of goals and constraints is then important. The postulated objective, which could be called economic surplus, is an approximation of one of those goals. Given the elements of economic calculation in farm household behaviour, it is an important goal of farm households. 2) Production functions are specified through the LUSTs, which are specific combinations of land units, land use types and technologies with fixed input and output quantities per hectare; the fixed input and output coefficients also include the sustainability parameters. Given the circumstances in the Atlantic Zone, soil nutrient depletion and biocide use are considered the most relevant sustainability criteria. However, the model is not comprehensive with regard to the number of land use types, and hence agricultural products, included. This was done in view of the emphasis on the development of a methodology for land use analysis. 3) Resource endowments with regard to land (per soil type) and household labour are specified per farm type and per month; the impact of the selected LUSTs on resources related to the sustainability parameters is appraised at both the farm as well as the sub-regional level. 4) The market for agricultural products is assumed to be unaffected by producer decisions in the sub-region: all products can be sold or purchased at a fixed price. However, with respect to the labour market it is assumed that working off-farm as hired labour on other farms inside the sub-region is limited by the aggregated demand for such labour, while off-farm work outside the sub-region on (banana) plantations is restricted;
wages are fixed, depending only on the type of work. 5) The policy environment is hardly specified, except in the scenarios restricting the impact on environmental resources.

### 5.2.2 Sustainability parameters in linear programming models

In contrast to other definitions of sustainable development, including Brundtland (WCED, 1987), Pearce and Turner (1990: 24) speak about "Maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time." Obviously, the net benefits of economic development do not only refer to benefits in the present. Benefits are spread over the years and thus involve an element of time. In a way, an attempt is made to compare the distribution of the benefits in a dynamic context.

Maintaining the services and quality of the stock of resources over time implies, as far as is practicable, acceptance of the following rules (Pearce & Turner, 1990: 24 & 44): a1) utilise renewable resources at rates less than or equal to the natural rate at which they regenerate, and a2) keep waste flows to the environment at or below the assimilative capacity of the environment; and b) optimise the efficiency with which non-renewable resources are used, subject to substitutability between resources and technical progress.

Sustainable development as defined above can easily be narrowed down to sustainable land use as a starting point for analysis. The given 'rules' for resource use can then be applied to the circumstances in a specific area. The main natural resources for land use are land and water. With regard to each of these resources, parameters can be designed to measure its quantity and quality. As noted earlier, soil nutrient depletion and biocide use are considered the most relevant sustainability criteria in the case study area in the Atlantic Zone in Costa Rica. These parameters can be related to rules a1) and a2), respectively, for resource use. Moreover, they can be thought of as the relevant sustainability indicators of the 'environmental (utilisation) space' with regard to land use in the research region.

Linear programming optimises resource use given a certain objective. In other words, it strives for an optimum efficiency, rule b), for

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86 This section is based on Schipper et al. (1995a).

sustainable development. Efficiency is optimised subject to substitutability between resources and technical progress. The effects of substitution can be traced via shadow prices of constraints and sensitivity analysis. The notion of 'technical progress' (or innovations, leading to a more productive use of resources) is part of the model: each land use type is specified according to technology and combined with a land unit (the LUSTs). In the optimal solution the most efficient technologies or LUSTs, and thus resource use, are chosen in view of all options and constraints.

Maintaining an objective based on economic behaviour, e.g. maximising farm economic surplus, implies that ecological sustainability criteria should be accounted for via constraints. This is also the approach in the different economic models regarding agricultural land conservation and environmental improvement in Heady & Vocke (1992). In such a set-up, each activity causes a positive or negative impact, expressed in 'technical' coefficients, on a sustainability constraint. The total impact of the sum of all activities is restricted by the 'Right Hand Side' coefficient, which should be an indication of the (renewable) resource availability and/or its regeneration rate, or, in case of pollutants, of the assimilative capacity of the environment. If desirable and possible, the economic costs of resource use or pollution can be deducted from the economic surplus in the objective function through auxiliary variables.

5.2.3 Single and multiple goal linear programming

(Regional) agricultural planning, or land use planning for that matter, aims at steering the development of the agricultural sector (of a certain region) in a specific direction. These directions can be represented by objectives or goals. Often, more than one goal is pursued at the same time. At the farm level, a farm household can strive for multiple goals: short-term cash income, food security, low risk, and long-term viability. At the policy level, goals include contributions to national income, the balance of trade and employment. Decision-making in the context of multiple goals - or more general multiple criteria - is not easy, as it requires weighting of goals by the decision maker. This is inherently subjective. However, the decision making process can be structured by models which calculate the contribution of each option to each goal, as well as the trade-offs between goals.

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88 This section is based on Erenstein & Schipper (1993: 6-7).
Recently, in the context of land use planning, a number of studies have appeared describing the application of interactive multiple goal linear programming (IMGLP) models. After a first round, in which the maximum and minimum value of each goal is established, an interaction with the decision maker(s) starts. Not every goal can be at its maximum at the same time. Therefore, the decision maker is asked to set certain minimum values for the different goals (as constraints or bounds) and to indicate which goal should be maximised. Then the model is solved. The decision maker will judge the results. If the decision maker is not content, new (tighter) limits will be set for a number or all of the goals, after which the model is solved again. The process can be repeated several times.

However, interactive multiple goal linear programming is not the only possible technique in the field of multiple criteria analysis. Multiple criteria analysis is a catchword for a multi-dimensional analysis of alternatives and comprises a collection of close to one hundred techniques that share some basic methodological aspects, but differ in other, mainly technical aspects (van Pelt, 1993: 40). Most are used to evaluate alternatives on the basis of discrete variables. Where the decision variables are continuous, linear programming based approaches could be used.

In the context of linear programming, in addition to interactive multiple goal programming, three other multi-criteria analysis techniques can be used: goal programming, multi-objective programming and compromise programming (Romero & Rehman, 1989). An application of compromise programming can be found in Erenstein & Schipper (1993). However, these multiple criteria methods are all based on the classical single goal - linear programming set-up. Activities, constraints and coefficients of the matrix are the same as in a linear programming model with a single objective function, except that in multiple criteria analysis the programming model is solved, in subsequent runs, with more than one objective function (each run with a different objective). Therefore,

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89 For a more extensive explanation and examples the reader is referred to Ayyad & van Keulen (1987), Fresco et al. (1992), Veeneklaas (1990b) and de Wit et al. (1988). An example of such a model (Veeneklaas, 1990a) was outlined in Section 5.2.1, together with a number of references to other models of this type.

linear programming models in land use analysis as outlined in the present
text, can be seen as forerunners of a subsequent analysis with multiple
criteria. Multiple criteria models are not investigated further here.

5.2.4 Linear programming and economic analysis in agriculture

As a method of analysis, linear programming is best suited to questions
of allocation of resources at the farm and sub-regional level for a given
set of market conditions. Econometric methods are better suited to
analyse product and factor markets at higher levels of aggregation. Linear
programming is more justified at the farm or sub-regional level than at
the regional, sectoral or national level, because of the assumption of fixed
prices. Relaxing that assumption, for example by incorporating
downward-sloping demand functions for relevant products, requires
quadratic programming models or linear approximations of non-linear
relationships. In that case, price elasticities should be estimated
econometrically.

Comparing linear programming and econometric analysis also
concerns the concept of production function, i.e. how the transformation
of inputs into outputs is perceived. A production function embodies both
agricultural and economic aspects. Farmers and agronomists alike often
think of yields, use of seeds, fertilizers and pesticides, and labour
requirements in terms of specific quantities per ha. This leads to the
construction of fixed input-output production functions, which can be
incorporated as activities in a linear programming model. These
production functions are of a discrete character, in accordance with the
perception of reality by many farmers and agronomists. Different
technical production options can be incorporated by including the
respective input-output vectors. Agronomists and farm management
specialists think equally in terms of inequalities, for example, labour use
versus labour availability per month (Hazell & Norton, 1986: 3-4). The
labour supply may then be exhausted in some months, with slack labour
existing in others. Linear programming methods are particularly suited to
deal with such inequalities.

However, economists (but also crop production ecologists; Jansen,
1994) are more inclined to think in terms of continuous production
functions. Such functions allow for econometric estimates of coefficients,
and are comparable with the use of crop growth simulation models. At
the level of the individual farm, for each LUST, continuous production

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91 This section is based on Schipper et al. (1995a).
functions are difficult to construct. Furthermore, at that level econometric estimation is impossible, while estimation of continuous functions with data collected from different farms meets theoretical objections (Ellis, 1993: 74-76). Econometric estimations of supply and demand elasticities, based on time series data, are more justified. However, objections can be made to these estimations as well (Hazell & Norton, 1986: 4-5). First, too many elasticities often have to be estimated from too few data, especially if there are many cross-elasticities. Second, the quality of the data is often inadequate, especially in developing countries. Third, the resulting estimates are based on aggregate historical data, not specified per technology and not taking into account new technologies.

The approach in the case study outlined in the next chapters is based on non-statistical point estimates of technical coefficients at LUST and farm level, with many technological options to evaluate. Therefore, the research team in the Atlantic Zone of Costa Rica opted for a linear programming approach. However, one has to realise that the solutions of linear programming models explain what would potentially be the best land use, but cannot indicate which solution will be chosen in reality. Also, it shows a potential 'future' situation, but not the way to reach such a situation. Mapping the road to potentially attractive land use patterns within the different farm types requires research into the links between policies and farm household decisions via markets, services and infrastructure, as discussed in Kuyvenhoven et al. (1995) and Kruseman et al. (1995).

5.3 Linear programming models in land use analysis

In the present section a sketch of linear programming models for an economic appraisal of land use is given. The approach followed is similar to the outline for agricultural sector models provided in Hazell & Norton (1986: 239-266). The emphasis will be on models for a sub-region, in which different farm types are distinguished.

A sub-region is considered to be a geographic part of a region, which in turn is a part of a country. The main difference between a region and a sub-region is the (relative) economic size in comparison to the size of a country. A sub-region is sufficiently small compared to the country, that neither the quantity of outputs nor inputs (including factors of production) produced or demanded influences their prices. In contrast, a region is considered an 'important' or 'large' part of the economy of a country. To illustrate the difference between a sub-region and a region, take the production of plantain in the Atlantic Zone of Costa Rica, where about
70% of the national production of plantain originates. With limited demand, it can be expected that a change in the plantain production in that zone will influence the price. On the other hand, in the Neguev the plantain production might be 5% of the zonal production, implying 3.5% of the national production. In this case, for all practical purposes it can be assumed that a change in the plantain production in the Neguev will have no influence on its price. Of course, this distinction between sub-region and region based on economic size is relative and might differ per product. In particular, if a certain sub-region specialises in one product, it might be important at the national level with regard to that product. Given the pragmatic distinction between a sub-region and a region, which must be assessed in practice case by case, we assume that prices are fixed in a sub-region for all outputs and inputs, while this is not necessarily so in a region.

Normally, within a sub-region one can distinguish different farming systems or farm types. Given the aggregation bias, it is therefore recommendable to define farm type specific activities and constraints. These farm type specific activities and constraints are incorporated into sub-matrices (one for each farm type) positioned in a block-diagonal manner in the overall sub-regional model.

Different aspects of linear programming sub-regional models are outlined below under the headings of objectives, variables and constraints.

Objectives

For an economic appraisal of different policy options it is desirable to have a descriptive or positive objective function in both agricultural sector and land use analysis models. This function should mimic a postulated objective of farm households, thereby introducing an aspect of farm household behaviour into the model. Farm households often have a strong element of economic calculation in their behaviour. Their decision making can then be approached as constrained optimisation. A measure of a farm economic surplus can be used as a first approximation of a suitable farm household objective function related to income earning of a
A linear programming approach to land use analysis

A linear programming approach to land use analysis

household\textsuperscript{92}. Such a function includes all benefits and costs from the farm household's point of view\textsuperscript{93}.

A first qualification of surplus maximisation could be the introduction of minimum consumption requirements, to be produced on-farm and/or purchased\textsuperscript{94} (or otherwise exchanged) elsewhere. Obviously, such

\textsuperscript{92} Obviously, such an objective function ignores the consumption side of the farm household. In models integrating household production and consumption the objective function could represent a measure of utility (Norton & Hazell, 1986: 66-71). Examples of such approaches for farm level models, while still using linear programming to model the production side, are Singh & Subramanian (1986) and Ruben et al. (1994). Extending this approach to (sub-)regional models can be questioned as it would involve the summation of utility over farm types. As interpersonal comparison of utility is often rejected, such summation is more difficult to justify. Moreover, even in the case of a single household, the problem remains of how to aggregate utilities derived from the consumption of different goods (Anderson et al., 1977: 76-100). This applies to aggregation of utilities per member of a household, as well as over the members.

\textsuperscript{93} Therefore, all prices of tradable outputs and inputs should be farm-gate prices. Factors of production that are not tradable in the model, are not valued in the objective function. This is often the case with land, but not necessarily so. If land is rented in or out on a regular basis, or otherwise exchanged between farms, these transactions could be built into the model (Hazell & Norton, 1986: 205-206, 258-259).

Hired labour and off-farm work are valued at the going wage rates, taking into account transaction costs. Labour can be exchanged between different farm types within a (sub-)region labour. This can be accomplished in the model in the same way as with land transactions.

A complication arises for household labour working on-farm. One approach might be to value household labour at the off-farm wage rate. However, farm households often have a preference for working on their own farm over off-farm work. By not valuing household labour (which would come down to a zero on-farm wage rate), the model will first use household labour before hiring labour. No one, however, would like to do work that does not earn a certain minimum return per hour worked (in view of the mentioned preference, lower than the off-farm wage). By rewarding household on-farm work with a wage equal to such a minimum return, the programming model will not select an activity with a return to household labour lower than the minimum return, while still employing household labour before hiring labour. The minimum expected return to household labour is often called a 'reservation' wage. A reservation wage can also be interpreted as reflecting the preference for leisure of a farm household.

\textsuperscript{94} Often such a minimum requirement can (partly) be purchased, or the surplus be sold. In that case, both purchasing and selling should be separate activities in the model, each with its appropriate price. The optimal solution will indicate whether (part of) the requirement is purchased, or a possible surplus is sold. Where the minimum consumption requirement must be produced completely on-farm, but can be sold in part, it can be valued at the going sales price. However, if in the latter case selling production above the (continued...
requirements are not part of the objective function, but can be formulated as constraints.

In more elaborate models, certain aspects of risk could be incorporated into the objective function through special variables in conjunction with risk specific constraints. As various approaches to risk in programming models are possible, depending on an assessment of the nature and types of risk (e.g. yields, prices) and of the attitudes towards risk of farm households, as well as on the data availability, it is beyond the scope of the present study to elaborate this theme.

In regional models, for those outputs of which production might influence its price, (competitive) markets can be modelled. In those cases the relevant exogenous price coefficients become endogenous variables. By introducing downward-sloping demand curves for the relevant markets, the sum of the producer and consumer surpluses in these markets can be maximised (Hazell & Norton (1986: 164-201). Comparable approaches can be followed in the case of endogenous input prices (Hazell & Norton, 1986: 201-206).

Variables

LUSTs form the nucleus of a land use model, usually measured in ha year\(^1\). As outlined earlier they consist of a land unit, a land use type and a technology specification. In that way the input and output coefficients can be specified completely. Which coefficients are to be specified depends on their relevance or usefulness. Each coefficient of a variable indicates the use of a constraint (inputs) or the supply to a constraint (outputs)\(^95\). Normally, LUSTs have output coefficients per product (main product, by-products) and input coefficients related to the use of land, labour and capital {capital goods (power sources, including animal

\(^{94}(...continued)\)

consumption requirement is not a realistic possibility, one can refrain from valuing it. In all instances the dual variable (shadow price) of the minimum consumption requirement constraint indicates its opportunity cost in terms of foregone economic surplus (the objective function).

\(^{95}\) The units of measurement of an input or output coefficient are the units of the constraint per unit of the variable. For example, if a labour constraint is expressed in days year\(^1\) and the LUSTs in ha year\(^1\), then the labour input coefficient is expressed in days ha\(^1\). Furthermore, it is an established convention that input coefficients have a positive sign and output coefficients a negative sign. In that way, the use of a constraint (input coefficient) has the straightforward interpretation of diminishing its availability, while the supply to a constraint (output coefficient) increases its availability.
traction, and/or equipment) or in the form of operating capital\{, and current inputs (e.g. seeds, fertilisers, biocides). Mostly, land and labour uses are defined for sub-periods within a year e.g. seasons or months, to account for seasonality. Furthermore, labour use could be specified per type of labour (e.g. male/female; labour for specific tasks, for example ploughing). The impact of LUSTs on the environment can be expressed in terms of input and output coefficients related to specific environmental or sustainability indicators.

As it is recommended to distinguish farm types within a sub-region, the LUSTs variables are specified per farm type. If the model is a multi-period model, extending the time-frame of one year, the LUSTs must also be specified for each of these periods, for example for each year.

It is not advisable to include the 'benefits less costs' (e.g. the value of production less current input costs) per LUST directly as a coefficient in the objective function. In that case, it can become cumbersome to change prices, unless a good matrix generator is available. It is better to introduce separate variables for outputs and inputs. Each of these can then have a pricing coefficient in the objective function. The value of the output and input variables is determined through constraints (also called 'balance' or 'accounting' rows) for each of these variables. Furthermore, the shadow price of these balance rows indicate the price of outputs and inputs, a feature which conveniently fits into economic theory, and which is especially useful where downward-sloping demand curves for outputs, or upward-sloping supply curves for inputs, are introduced. In this case special demand (or supply) variables are introduced indicating segments on the demand (supply) curves. In the balance rows these variables are multiplied by coefficients representing the related demand (supply) quantities (Hazell & Norton, 1986: 170-172, 204-205).

Normally, labour variables should be introduced per farm type for hiring labour and for off-farm work. Again, distinctions could be made according to type of labour and work, in accordance with the differentiation in the labour use coefficients of the LUSTs. Also, these labour variables are specified according the same (sub-)periods. The relevant wages figure as objective function coefficients.

In the same vein, environmental or sustainability variables could be formulated, indicating the overall impact of each indicator at the relevant

\[96\] However, a warning is in place. Each distinction has a tendency to multiply itself in terms of related constraints and variables, making models larger and larger, and therefore less manageable and insightful. Furthermore, it creates additional burdens in terms of data needs and computer capacity.
aggregation levels (land unit, farm type, sub-region, region). If these overall impacts can be valued, the value could be deducted from the economic surplus in the objective function. In that case, such valuation is taken into account in the optimisation process, indicating that decision makers, in this case farm households, take into account the environmental consequences of land use decisions in order for their surplus to be maximised. An alternative could be to deduct the value of the environmental impact from the economic surplus after the optimisation, thus as a post-model calculation. It would show the consequences of the environmental impacts on the surplus, in case these impacts are not part of the objective function.

In addition to LUSTs which use land in a direct way and which unit of measurement is often expressed in hectares, there are activities that use land indirectly, for example animal production systems (APSs). The size of these activities is normally measured in animal units. The relation with land use is not a simple one, as stocking rates might differ between the various methods of keeping animals (implying different technologies, each denoting an APST), but also between dry and wet seasons. Also, animals might receive supplementary feed from fodder crops produced elsewhere on the farm, or purchased from inside or outside the (sub-)region. In the case of stall-fed animals, direct land use can even be neglected. In these cases, it can be said that APSTs use land indirectly by claiming land for LUSTs (via input-output relations).

A last group of variables mentioned here are those related to aspects of risk. Risk is important for decision making in agriculture and therefore affects land use. Farming is inherently a risky business, and especially so in developing countries. Risks are often related to yields and prices, but the availability of inputs cannot be certain either. Empirical studies show that most farmers are risk-averse (e.g. Binswanger, 1980; Dillon & Scandizzo, 1978). Such farmers prefer land uses that provide an acceptable level of security even if this means sacrificing income on average. More secure plans may involve dedicating less land to risky activities, diversifying into a greater number of activities to spread risk and using known technologies instead of new ones. In the case of small farms, a larger share of the consumption requirements will be grown on-farm. Ignoring risk-averse behaviour in farm planning often leads to results that are unacceptable to farmers, or that bear little relation to decisions regarding land use taken in reality (Hazell & Norton, 1986: 76-77).

However, Huijsman (1986: 270) has cautioned that: "precise quantitative answers to the question of risk-induced economic inefficiencies are of minor importance to many issues that directly
Concern farmers and affect agricultural development." More important than to know how and to what extent farms avoid risk for building it in models, is the study of how farmers deal with environmental (biophysical and socio-economic) variability, and whether ways can be found to assist farmers in making better informed decisions and/or to improve their environment in this respect. Modelling risks can be become very complicated and often demands extensive (non-existing) data, which is difficult or even impossible to collect. Therefore, although risk is an important issue, it should not hinder the development of more simple land use models.

**Constraints**

In sub-regional land use models, land unit constraints are formulated in relation to the LUSTs variables, for each farm type and (sub-)period, per relevant distinction in land units. These distinctions relate to, for example, rainfall regimes and altitude classes, rainfed or irrigable land, or soil types.

In addition to land constraints, labour constraints are normally part of land use models. In view of the often marked differences in labour use in different periods within an agricultural year, labour constraints are formulated per sub-period, e.g. per month or for certain peak periods. To enable a certain flexibility in labour use per period, labour availability in each period could be relatively large, but more restricted for the year as a whole. Household labour is constrained per farm type, while hired labour and off-farm work is constrained at the level of the sub-region. The constraints can be made specific for each type of labour. The most elegant way to combine labour variables with labour constraints is to first introduce labour accounting rows, in which the demand for labour by LUSTs and APSTs is balanced by the supply of labour from each source (household labour, hired labour), per (sub-)period and labour type. Subsequently, each labour source, combined with off-farm labour work, is then limited in each (sub-)period at the appropriate level (farm type, (sub-)region). When appropriate, a structure comparable to labour constraints can be set up for capital constraints.

Following the outline for output and input variables for aggregating the productions and input uses by LUSTs (and APSTs), appropriate balances for these outputs and inputs can be formulated. Accounting rows for balancing outputs from LUSTs with inputs demanded by APSTs and vice versa require special attention. Examples are fodder, animal traction and manure. Fodder, being a main product from fodder LUSTs or a by-product from other LUSTs, is often split into its main components for
animal nutrition, for example dry matter, energy and protein. On the other hand, APSTs require certain quantities of these components in order to stay alive, grow and produce. Mostly, it will be necessary to formulate the nutrition balances on a monthly basis, or at least per season. Provisions must be made for selling and purchasing fodder. The same applies to animal traction and, perhaps, manure.

In the case of limited demand for outputs or a limited supply of inputs at the (sub-)regional level downward-sloping demand or upward-sloping supply curves can be approximated in linear programming models. This is accomplished by defining demand or supply variables each indicating alternative segments of the demand or supply curves. Multiplied by coefficients representing the related quantities, these variables are linked to the appropriate balance rows. By restricting the sum of these variables to one, and because of the convexity of the problem, only one or a combination of two adjacent demand or supply variables will be selected. Such constraints are often called ‘convex combination’ constraints (Hazell & Norton, 1986: 170).

After this general outline of a possible set-up for linear programming models in land use analysis, the next chapter develops the precise formulation of the model in the Neguev area in Costa Rica. In Chapter 7, results of scenario studies using this model will be presented.
6 A LAND USE MODEL OF THE NEGUEV

6.1 The setting

This chapter presents a sub-regional linear programming model that has been constructed for the Neguev settlement. For convenience the model is referred to as REALM (Regional Economic Agriculture Land-use Model). The approach to land use analysis aims at deriving relevant options for land use by balancing economic criteria for agricultural production on the one hand and ecological criteria on the other. Model results are presented in Chapter 7, where land use scenarios are analysed to examine whether incomes of farms in the Neguev can increase through an improved land use from the point of view of sustainability.

An important aspect of the methodology is the differentiation between levels of analysis, in analogy with those in the LEFSA (Land Evaluation & Farming Systems Analysis) sequence in Fresco et al. (1992: 51). At each level of analysis different decisions are made. In the Neguev settlement as a sub-region of the Northern part of the Atlantic Zone of Costa Rica, land use decisions are made at the farm level, influenced by policy decisions at the national level, and, albeit progressively less important, at the regional and sub-regional levels. Up to now only three levels of analysis (LUST, farm and sub-region) have been incorporated into the methodology of land use analysis. However, in the linear programming model two levels of decision making are incorporated: land use decisions at the farm level and policy decisions at the sub-regional level, the latter thus including decision-making at levels ‘higher’ than the farm level.

Furthermore, because of aggregation issues, modelling land use is complicated. One way or another, reality needs to be simplified. In the

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97 With the exception of Section 6.6, this chapter is based on Schipper et al. (1995a).

98 Of the three meanings mentioned in Webster’s Third New International Dictionary, the first, kingdom, is obviously not in anyway connected to the model, neither in its purpose nor scope. However, the second and third meanings are relevant. The second meaning is region, territory or sphere, domain, range, and the third, any of several major biogeographic divisions: as a) a primary marine faunal division, b) a primary terrestrial division consisting of one or more parts, and c) a division coordinate with a biogeographic region.
methodology, the first aggregation issue - decision-making both at the farm as well as at the (sub-)regional level - is approached by using a plausible objective function (for farm households) for a linear programming model: maximisation of the difference between the value and the cost of production, including household and hired labour, plus off-farm earnings. This objective function can be called *economic surplus* and is calculated as the farm household income minus a valuation of on-farm household labour. In that way the effects of policies at the sub-regional level on land use decisions can be studied. The second aggregation issue - aggregation bias - is diminished by incorporating five farm types in the sub-regional model, each with specific resource availabilities with regard to land, specified according to six types, and to household labour. The third aggregation issue - exogenous variables becoming endogenous - is side-stepped by supposing that the sub-region is sufficiently ‘small’ in relation to the country and that supply from the sub-region is too small to influence prices of products. On the other hand, a restricted sub-regional labour supply forms part of the model: all farms together cannot hire more labour than is available within the sub-region. However, the price of hired labour is fixed.

The linear programming model developed here is part of the USTED (*Uso Sostenible de Tierras En el Desarrollo*) methodology and its related software MODUS (MOdules for Data management in USted), as described in Stoorvogel *et al.* (1995). Figure 6.1 provides an overview of USTED. Essentially, the linear programming model receives input and output coefficients of land use activities (LUSTs) and output prices from MODUS. After optimisation, it returns the solutions to MODUS, which prepares maps and generates numerical reports to facilitate the interpretation of the solutions. Thus, MODUS operates as a ‘pre’-matrix generator and a ‘post’-report writer for the linear programming module, since the linear programming software OMP (Beyers & Partners, 1993) has its own matrix and report generators.

Before presenting the model in detail, a profile of the case study area, the Neguev settlement, is provided (Section 6.2). REALM is then presented in general terms regarding land use systems (section 6.3), farm types (Section 6.4) and the sub-regional model (Section 6.5). The full model is described in Section 6.6.\(^{99}\)

\(^{99}\) A version of REALM written in the modelling language of the OMP software can be obtained from the author.
6.2 The Neguev settlement

The Neguev settlement (approximate location 83°33'E and 10°12'N) has an area of 5,340 ha (Figure 6.2). The altitude is between 10 and 50 m above sea level in a region where climate is classified as very humid tropical, without dry months (Herrera & Gómez, 1993). The average annual rainfall is 3,630 mm (1972-1988) with an air temperature of about 25°C (1976-1988; average between daily maximum and minimum temperatures). Soils in the area are classified into three types (De Bruin, 1992): 1) young poorly-drained volcanic soils of relatively high fertility.
(Entisols and Inceptisols), 2) young alluvial well-drained volcanic soils of relatively high fertility (Inceptisols and Andisols), and 3) old well-drained soils developed on fluvio-laharic sediments of relatively low fertility (Oxisols and Inceptisols).

Figure 6.2 Location of the Neguev settlement

The settlement originated when squatters occupied land of the hacienda Neguev in September 1979. The IDA (Instituto de Desarrollo Agropecuario) divided the Neguev into farms of 10, 15 or 17 ha. Later, a
number of farms were sub-divided further (IDA, 1985). Farmers were not allowed to sell or rent their land until 1991. Nevertheless, unofficially, many farmers did leave their farms in view of the difficult farming circumstances. In these cases the farms were, de-facto, rented to other farmers or the 'improvements' (mejoras) were sold\textsuperscript{100}. For the sake of the case study, the Neguev is considered to be sub-divided into 307 farms with a total area of 4,236 ha available for agriculture or forestry (Figure 6.3). The settlement is divided into two parts, separated by the river Parismina. The Northern part is relatively easily accessible, whereas the Southern part is more isolated. The Southern part is by far the largest of the two. Although its main entrance road is connected to the highway San José-Limón, no bus service was provided until 1992, when a second entrance road was created. Until the introduction of this twice daily bus service, the minimum walking distance to the highway was about six km, while the maximum distance was about 14 km, which had a negative impact on the marketing possibilities and prices of the different crops in this part of the Neguev (Portier, 1994: van Tilburg et al., 1995).

The tasks of the IDA consisted of providing titles, extension, credit through the Caja Agraria and marketing assistance to the farms, and creating a simple infrastructure: rural roads and five small villages with a communal centre, a primary school, a soccer field and one or two small shops. No electricity or telephone lines were installed, except in the main centre, Milano, where the head office of the IDA is also located. The IDA executed programmes to stimulate the cultivation of crops like cacao, chile, palm heart, passion fruit, pineapple, roots and tubers\textsuperscript{101}.

The average farm size is 13.8 ha, with 1.2 ha fertile poorly-drained soil, 3.2 ha fertile well-drained soil and 8.6 ha unfertile well-drained soil. Except for a few larger farms, the farm size is fairly uniform (Schipper, 1993: 6-7). However, the three soil types are not equally distributed over the farms; for details see Section 6.4 and Table 6.2.

\textsuperscript{100} More details on the history of the Neguev settlement can be found in Rojas & van Sluys (1990), Rojas & Waaijenberg (1990) and de Vries (1992).

\textsuperscript{101} Details of some of these programmes can be found in a number of field reports of the Atlantic Zone Programme (note 63): cacao (de Groot, 1987), palm heart (de Haan & Waaijenberg, 1992), and roots & tubers (Stolzenbach, 1990). Mudde (1987) analysed the interactions between personnel of the IDA and farmers. As these relations are not without tensions (Rojas, 1990), caused by the violent history of the occupation of the Neguev, differences among farmers, and policies and attitudes of the (personnel of the) IDA, de Vries (1992) studied the 'interface' between the farmers and the IDA.
Land use in the period 1985 to 1991 can be observed in Table 6.1. Pasture and forests are still the major land uses. As part of a structural adjustment programme, the government of Costa Rica changed its price support policy for basic food crops (including maize, rice and beans) in 1988. The farm-gate prices for these crops went down in real terms, leading to some major changes in land use. Around 1991, annual crops, in particular maize, were cultivated much less than in the period 1985 to 1987. This is in contrast to perennial crops like palm heart and plantain.
A land use model of the Neguev

which were cultivated more in the later years than in the earlier. Lastly, the area of cassava fluctuates, possibly in response to market and price conditions.

Table 6.1 Land use in the Neguev: 1985, 1987, 1989 and 1991 (ha)

<table>
<thead>
<tr>
<th>Major land use type &amp; crop</th>
<th>1985 1</th>
<th>1987 2</th>
<th>1989 3</th>
<th>1991 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annuals</td>
<td>460</td>
<td>998</td>
<td>282</td>
<td>356</td>
</tr>
<tr>
<td>Perennials</td>
<td>238</td>
<td>364</td>
<td>335</td>
<td>383</td>
</tr>
<tr>
<td>Pasture</td>
<td>2346</td>
<td>1745</td>
<td>2519</td>
<td>2407</td>
</tr>
<tr>
<td>Forest &amp; wasteland</td>
<td>1194</td>
<td>1073</td>
<td>1101</td>
<td>1090</td>
</tr>
<tr>
<td>Total</td>
<td>4236</td>
<td>4236</td>
<td>4236</td>
<td>4236</td>
</tr>
<tr>
<td>Maize</td>
<td>414</td>
<td>589</td>
<td>181</td>
<td>154</td>
</tr>
<tr>
<td>Cassava</td>
<td>30</td>
<td>118</td>
<td>76</td>
<td>187</td>
</tr>
<tr>
<td>Pineapple</td>
<td>-</td>
<td>90</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Plantain</td>
<td>-</td>
<td>23</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>Palm heart</td>
<td>-</td>
<td>-</td>
<td>90</td>
<td>138</td>
</tr>
</tbody>
</table>

1 IDA (1985): based on an inventory of all farms.
2 Based on Waaijenberg (1990: 41); extrapolation of a random sample survey of 53 farms.
3 Based on Mülcher (1992: 25-42 & 59) who presents an aerial photo interpretation of six non-randomly selected sample areas with a total area of 1,273 ha; the areas per land use type for the Neguev as a whole are obtained by weighting the sample data with the area of the three main soil types.
4 Based on Mülcher (1992: 44-51), who also corrected the 1989 aerial photo interpretation for observed changes in 1991.

For those interested in farming and land use in the Neguev, more details are provided in Appendices 3 and 4. In Appendix 3 farming and land use in the Neguev in 1987 is presented, while in Appendix 4 the situation in 1991/92 is described. Both appendices are based on surveys carried out in the respective years. The information enables readers to obtain an insight into ways of farming and types of land use in these years, as well as in the differences between 1987 and 1991/92. Furthermore, the information on farming and land use in these years
provides a perspective for the results of the different scenarios in Chapter 7.

The 1991/92 farm survey was held to establish relationships between land units, land use types, input and factor use, outputs, and economic returns. These points are in line with the topics for land use oriented surveys outlined in Section 4.5.2.1. The results are mainly used to construct 'present' LUSTs: land use systems based on actual technologies currently practised on real farms (Section 7.3; Jansen & Schipper, 1995). As it was necessary to obtain detailed data of good quality, it was felt that a multi-visit survey, visiting the farms every week for at least a year, was appropriate. Given the limited means of the programme only a small number of farms could be studied. Details of the survey are included in Appendix 4.

6.3 Land use systems as core activities in the models

Land use activities (LUSTs) are pivotal in REALM. They are defined as a combination of a land unit and a land use type with a specified technology. At present, the model contains six land units (three soil types, either with or without a forest cover at present) and eight land use types: cassava, logged forest, maize, palm heart, pasture with cattle, pineapple, plantain and tree plantation. For each land use system different technologies, present as well as potential, are specified. Each LUST is described quantitatively as a sequence of operations (Jansen & Schipper, 1995), and summarised in input or output coefficients (quantities or values per ha) for use in the linear programming model: land use, labour requirements, costs of current inputs (sum of input quantities times prices), labour costs, production specified per product, soil nutrient depletion with regard to nitrogen (N), phosphorus (P) and potassium (K), and a biocide use index value. The coefficients are either averages per month (land and labour use) or per year (soil nutrient depletion of N, P and K, and the biocide use index value), or annuities of the present value over the life-span of the LUSTs (production, input costs and labour use), assuming constant prices over time.

The use of annuities needs a brief explanation. A number of LUSTs are perennials. These LUSTs occupy land for a number of years. In the early years costs are higher than benefits, while the reverse is true in the later years. As REALM is a one period model (one year consisting of 12 sub-periods, the different months in a year), values in different years must be added. However, values that occur in an earlier year are worth
more than those that occur later. A discount rate\textsuperscript{102} is used to value future cost and benefits in today's terms in order to calculate their present values. Discounting future values to the present is normally (e.g. in Cost-Benefit Analysis) done with values, calculated by multiplying price by quantity. If one assumes constant prices over time\textsuperscript{103}, discounting can also be applied to quantities, for example, production (in kg or other physical units) or labour use (in hours or days) of a LUST in different years. After calculating such a 'present quantity', this can be multiplied by its price to obtain the present value.

However, perennial LUSTs occupy land for a different number of periods, for example, depending on land unit and technology, five years for plantain and 15 years for palm heart. Their present values must be made commensurable. Furthermore, the model contains annual LUSTs, e.g. maize, or LUSTs that occupy land for more than one year but less than two years, for example one of the cassava LUSTs. Another complication arises as maize, an annual crop, occupies land for only a part of the year. Present values based on time periods of different length, including lengths of one year or less, can be made commensurable by converting them to an annuity. The annuity is calculated through the capital recovery factor\textsuperscript{104}.

\textsuperscript{102} As the level of the appropriate discount rate is not a subject of the present study, it is assumed that the discount rate used (10\%) is a reasonable approximation of the opportunity cost of capital under the conditions in Costa Rica in the early 1990s. In one of the scenarios the sensitivity of the model for different discount rates is studied (Section 7.9).

\textsuperscript{103} Constant prices are, of course, a basic assumption in linear programming models of the kind discussed here. Moreover, even in models where we cannot assume an infinitely elastic demand for a product, thus where downward sloping demand curves are introduced (Section 5.3), we implicitly have to assume a constant price over time, albeit determined endogenously by the model 'once and for all'. In the case of multi-period models, in which demand curves would be specified for each period, there could be different prices in different periods for the same product. However, in such a model the need to work with (net) present values and/or annuities disappears. In that case output (and inputs) can be priced according to prices in each period (all prices are relative prices; a rise of the general price level, inflation, is not considered). Of course, subsequent valuing of costs and benefits in different periods can still be done by making use of a discount rate (including a zero discount rate), so that they can be properly added.

\textsuperscript{104} In financial terms, the capital recovery rate can be described as the level of payment ($A$) to be made at the end of each of $n$ periods to recover the present amount ($P$) at the end of the $n^{th}$ period at the discount rate of $i$ (Gittinger, 1982: 433). In a formula:

(continued...)
6.4 Farm classification and models

Day (1963) has formulated three criteria for the classification of individual farms into groups in order to obtain a perfect aggregation in linear models (Section 4.5.1). All farms in one group must have: 1) proportional revenue expectations per unit activity (proportional objective function coefficients), 2) the same technology for each activity (the same coefficients in the matrix of constraint use for each activity), and 3) a proportional availability of resources (proportional availability of constraining factors). These requirements are very demanding and in practice impossible to achieve (Hazell & Norton, 1986: 146-148). Therefore, it is only possible to approximate homogeneous groups by classifying farms according to, for example, agro-climatic zone, major soil type, distance to markets, availability of irrigation, crops cultivated or farm size. In the present case, all farms within the Neguev are located in one agro-ecological zone. All farms can cultivate the same crops. Also, because linear programming is used to determine land use, it does not make sense to classify the farms according to present land use. However, farms differ especially with regard to soil types and objectives. As a first step, it was decided to classify farms into farm types based on the main resources available for farming: land and labour. According to the third criteron of Day (1963), the proportional availability of resources is important. Therefore, farms were classified according to farm size and the relative availability of each of the three soil types, i.e. fertile poorly-drained (SFP), fertile well-drained (SFW) and unfertile well-drained (SUW) (Figure 6.4). Combined with an assumed constant average labour availability, the farms in the resulting groups are similar in their land to labour ratios.

\[ A = P \frac{i(1+i)^n}{(1+i)^n - 1} \]

In the actual calculations in USTED, the period \( n \) is one month; however, the annuities are expressed per year.
The farm groups were formed with the help of cluster analysis\textsuperscript{105}. The clustering was based upon the area of each farm (relative to the largest farm) and the proportion of each of the three soil types. The proportion of the soil types was calculated from a digitalised soil map of the Neguev (scale 1:20,000; de Bruin, 1992) overlaid with a map of the IDA farms (parcelas) at the same scale. The question of how many groups should be formed is often a matter of good judgement and convenience (Hair \textit{et al.}, 1992). Five groups of farms (types) were formed which are relevant in the light of local experience, four groups of ‘small’ farms (average farm size 14 ha) and one group with ‘large’ farms (average size 32 ha) (Figure 6.5). The four groups of small farms differ according to the importance of the soil types. Three groups out of these four have one dominating soil type, SFP in farm type 1, SFW in farm type 4 and SUW in farm type 5, respectively. The fourth group of small farms (farm type 3) has about as much SFW as SUW soils. The group of large farms has mostly SUW soils (farm type 2). The results of the clustering are summarised in Table 6.2. The respective land-labour ratios are based on an assumed labour availability of 2.0 labour-years per household.

Farms were not classified according to the objective(s) of the farm household. The main reason is the absence of sufficient reliable information. Attempts to sub-divide farm types into different farm household types, or ‘farmer’ types (Alfaro, 1993; Akkermans, 1993), have not yet resulted in usable classifications. Another difficulty with a farm household type classification based on objectives is related to the linear programming set-up. Within one (sub-)regional model different objectives for different farm types (or farm household types) are difficult to perceive, as a linear programming model has only one objective function, namely the sum of the (weighted) objective functions of each farm type.

\textsuperscript{105} Two clustering approaches were used, an hierarchical agglomeration schedule, ‘CLUSTER’, and a non-hierarchical technique, ‘QUICK CLUSTER’, both procedures from Norušis/SPSS (1990).
Figure 6.4  Soil types in the Neguev settlement
Figure 6.5 Farm types in the Neguev settlement
Table 6.2  Clustering of Neguev farms into five groups

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Number of farms</th>
<th>Average area (ha)</th>
<th>Area with soil type (%)</th>
<th>Land/labour ratio (ha labour-year$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SFP$^1$</td>
<td>SFW$^2$</td>
</tr>
<tr>
<td>1</td>
<td>33</td>
<td>15.7</td>
<td>60</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>32.1</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>13.5</td>
<td>7</td>
<td>52</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>14.1</td>
<td>3</td>
<td>91</td>
</tr>
<tr>
<td>5</td>
<td>189</td>
<td>13.1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>total/average</td>
<td></td>
<td>307</td>
<td>13</td>
<td>23</td>
</tr>
</tbody>
</table>

$^1$ SFP: Fertile poorly-drained soil
$^2$ SFW: Fertile well-drained soil
$^3$ SUW: Unfertile well-drained soil

In the sub-regional linear programming model REALM, a number of variables are included per farm type: LUSTs and the use of farm household and hired labour. Farm household labour can either work on-farm or off-farm. Off-farm work consists of two types: work on other farm types within the Neguev, or on a (banana) plantation outside the Neguev. All labour variables are specified per month.

In addition to variables, a number of constraints are stipulated per farm type as well: the availability of land, specified per land unit$^{106}$, and the availability of household labour$^{107}$, both specified per month. The latter is also specified per year$^{108}$. Furthermore, depending on the

$^{106}$ Equation (6.8) in Section 6.6.

$^{107}$ Equations (6.9)-(6.10) & (6.14).

$^{108}$ Equation (6.11).
A land use model of the Neguev

(variant of the) scenario, the constraints with regard to soil nutrient depletion\textsuperscript{109} and biocide use\textsuperscript{110} can also be specified per farm type.

6.5 Sub-regional models with farm types

In REALM, the sub-regional model of the Neguev settlement acts as a shell around the five farm type models, with the sub-matrices of each farm type model positioned in a block-diagonal manner in the matrix of the sub-regional model. The shell around these sub-matrices contains common constraints with regard to available employment on plantations outside the Neguev, and with regard to the availability of hired labour, both on a monthly basis.

The availability of employment opportunities on plantations is restricted to 50\% of the available household labour\textsuperscript{111}. The reasoning behind this restriction is that common employment contracts with banana companies last for three months only, with three months compulsory waiting before resuming work for the same banana company. In this way the company avoids part of the social security payments. Another restricting factor to the availability of plantation employment is the fact that the majority of the male labourers are young men, as the type of work is physically demanding.

Hired labour on one farm type is restricted by the available off-farm labour from the other farm types within the Neguev\textsuperscript{112}. This is a mutual constraint, as for every month the supply of off-farm labour is equal to the demand for hired labour within the Neguev. In other words, inside the Neguev farmers or their sons, work on the farms of their 'neighbours' and vice versa. This way of modelling the 'labour market' inside the Neguev is a reasonable first approximation of reality. As the location of the Neguev is rather isolated, it is less likely that outsiders look for employment inside the Neguev; the more so, because the observed wage rate is low in comparison to wages on (banana) plantations outside the Neguev, while unemployment is not high.

\textsuperscript{109} Equations (6.18)-(6.19) & (6.22)-(6.23).

\textsuperscript{110} Equations (6.26)-(6.27).

\textsuperscript{111} Equation (6.12) in Section 6.6.

\textsuperscript{112} Equation (6.13).
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The sub-regional model also contains constraints with regard to soil nutrient depletion\textsuperscript{113} and biocide use\textsuperscript{114}. In this way, rules a1 and a2 for resource use of the Pearce & Turner definition of sustainable development are also incorporated into the model at the sub-regional level.

The objective function of the sub-regional model consists of the net benefits to all farms, the \textit{economic surplus}, defined as the value of production, less input costs, less hired labour costs, less value of on-farm household labour, plus off-farm work labour income. The objective function is the sum of the same objective functions of each farm type.

6.6 Formulation of the linear programming model REALM

The linear programming model REALM of the sub-region Neguev consists of 29 groups of constraints or equations. In this section a complete specification is given. The symbols used are defined in three tables following the equations: indices in Table 6.3, variables in Table 6.4 and coefficients in Table 6.5.

As outlined earlier, the objective function is meant to represent an economic surplus. It is calculated as 'benefits less costs: value of production, less current input costs, less base labour costs\textsuperscript{115}, less hired on-farm labour costs, plus off-farm work labour income' (\$ year\textsuperscript{-1}). All monetary values are expressed in \textit{Colones} (\$), the currency of Costa Rica.

\[
\text{Max } Z = \sum_j p_j Q_j - \sum_{i=1}^{i=1} C_{i=1} - \sum_{i=2}^{i=2} C_{i=2} - \sum_m w_m H_m + \sum_o \sum_m z_{om} O_{om} \tag{6.1}
\]

The objective function is maximised subject to a number of constraints. These constraints, or, to use a more general term, equations, consist of real constraints and balances. Real constraints \{equations (6.8), (6.10)-(6.14), (6.19), (6.21), (6.23), (6.25), (6.27) & (6.29)\} can restrict

\textsuperscript{113} Equations (6.20)-(6.21) & (6.24)-(6.25).

\textsuperscript{114} Equations (6.28)-(6.29).

\textsuperscript{115} The base labour costs are equal to the annuity of labour use valued at the reservation wage, which is equal to the value of on-farm household labour.
the objective function; if binding, the value of the objective function is less than without such a constraint. Balance equations \{equations (6.2)-(6.7), (6.9), (6.15)-(6.17), (6.18), (6.20), (6.22), (6.24), (6.26) & (6.28)\}, or accounting rows, serve merely for calculating certain variables for easy pricing in the objective function, and/or for the computation of an aggregate. However, they do not restrict the value of the objective function. The specification of the equations is as follows.

Balances for each product, in which the physical production figures per LUST are summed in order to obtain production per farm type & total production, are expressed as annuities (Section 6.3) of present quantities (kg \text{year}^{-1} or 'units' \text{year}^{-1}).

\[
\sum_s \sum_l \sum_t -y_{jftlt} X_{jftlt} + Q_{jft} \leq 0 \quad \text{all } j, f \tag{6.2}
\]

\[
Q_j - \sum_f Q_{jf} \leq 0 \quad \text{all } j \tag{6.3}
\]

Balances for input cost (\(i=1\)), in which the input costs per LUST are summed to obtain input costs per farm type & total input costs; expressed as annuities (Section 6.3) of present values (£ \text{year}^{-1}).

\[
\sum_s \sum_l \sum_t c_{i=1,ftlt} X_{ftlt} - C_{i=1,ft} \leq 0 \quad \text{all } f \tag{6.4}
\]

\[
-C_{i=1} + \sum_f C_{i=1,ft} \leq 0 \tag{6.5}
\]

Balances for labour use (\(i=2\)), in which the annual labour use per LUST are summed to obtain the annual labour use per farm type & total annual labour use (called base labour in objective function); expressed as annuities (Section 6.3) of present quantities (hours \text{year}^{-1}). The purpose is to get a proper valuation of labour costs in a one-period model in a multi-period setting. As most labour is household labour, it is valued in the objective function at a reservation wage (Section 5.3). These equations are not used for balancing household labour with hired labour and off-farm work possibilities, as this is performed on a monthly basis in equations (6.9) to (6.14), in which calculations are made using monthly,
un-discounted, average requirements and availabilities. Subsequently, in the objective function, the average monthly hired and off-farm work amounts are valued at market wages.\textsuperscript{116}

\[ \sum_s \sum_l \sum_t c_{i=2,{}_{l,{}_{t}}} X_{f_{l,u}} - C_{i=2,{}_{f}} \leq 0 \quad \text{all } f \] \hspace{1cm} (6.6)

\[ -C_{i=2} + \sum_f C_{i=2,{}_{f}} \leq 0 \] \hspace{1cm} (6.7)

Sum of land use by LUSTs per farm type per land unit per month, constrained by land availability per farm type per land unit per month (ha year\textsuperscript{-1}).

\[ \sum_l \sum_t a_{f_{l,m}} X_{f_{l,u}} \leq b_{f_{m}} \quad \text{all } f, s, m \] \hspace{1cm} (6.8)

Sum of average labour use by LUSTs per farm type per month, balanced by on-farm household and hired labour supply per farm type per month (hours year\textsuperscript{-1}).

\[ \sum_s \sum_l \sum_t e_{f_{l,m}} X_{f_{l,u}} - F_{f_{m}} - H_{f_{m}} \leq 0 \quad \text{all } f, m \] \hspace{1cm} (6.9)

\textsuperscript{116} Once prepared to discount labour use on a yearly basis, why not do the same on a monthly basis and confront these labour requirements with monthly discounted labour availabilities? Strictly speaking, this could be done: as well as discounting the labour use per month flow variables in a particular year, one has to discount the labour availability per month stock variable in a particular year. The latter would imply that labour availability in a later year has less value than in an earlier year. As such a reasoning could (and should, to be consistent) be extended to other resources as well, for example land, we refrained from discounting the monthly labour uses and availabilities. Besides, the possible error is not important, as hired labour (or working off-farm within the Neguev, which is the same in the aggregate) is small in comparison to household labour working on-farm.
On-farm household and off-farm work, constrained by household labour availability per farm type per month (hours year\(^{-1}\)).

\[
F_{fm} + \sum_{o} O_{ofm} \leq g_{fm} \quad \text{all } f, m \quad (6.10)
\]

On-farm household and off-farm work, constrained by household labour availability per farm type per year (hours year\(^{-1}\)). In comparison to equation 10, the availability per year \((g_f)\) is less than the sum of the monthly availabilities \((\sum_m g_{fm})\). In that way labour must work less in some months to compensate for working more in other months (maximum number of days in a month less five; totalling per year 305 days per labour-equivalent), in order to work only a limited number of days per year (maximum 250 days per labour-equivalent).

\[
\sum_m F_{fm} + \sum_{o} \sum_m O_{ofm} \leq g_f \quad \text{all } f \quad (6.11)
\]

Sub-regional plantation (outside the Neguev; \(o=2\)) off-farm work availability per month (hours year\(^{-1}\)).

\[
\sum_f O_{o=2,fm} \leq p_{o=2,m} \quad \text{all } m \quad (6.12)
\]

Sub-regional hired work, summed over the farm types, per month, balanced by the availability of off-farm labour of all farm types together within the Neguev \((o=1)\) (hours year\(^{-1}\)).

\[
\sum_f H_{fm} - \sum_f O_{o=1,fm} = 0 \quad \text{all } m \quad (6.13)
\]
Hired work availability per farm type per month, which is not more than the sum of the off-farm labour of the other farm types within the Neguev; \( o = 1 \) (hours year\(^{-1}\)).

\[
H_{f=q,m} - \sum_{f \neq q} O_{o=1,fn} \leq 0 \quad \text{all } m, \ q=1,2,3,4,5 \quad (6.14)
\]

Labour: calculation of sub-regional total household labour, on-farm work per month (hours year\(^{-1}\)).

\[
\sum_{f} F_{f,m} - F_{m} \leq 0 \quad \text{all } m \quad (6.15)
\]

Labour: calculation of sub-regional total hired labour, on-farm work per month (hours year\(^{-1}\)).

\[
\sum_{f} H_{f,m} - H_{m} \leq 0 \quad \text{all } m \quad (6.16)
\]

Labour: calculation of sub-regional total household labour, off-farm work per month, specified per off-farm work type (hours year\(^{-1}\)).

\[
\sum_{f} -O_{of,m} + O_{om} \leq 0 \quad \text{all } m, \ o \quad (6.17)
\]

After the balances and restrictions regarding production and input, land and labour use, equations related to the sustainability indicators of soil nutrient depletion and biocide use are provided.

The data on nutrient depletion per LUST are aggregated for each nutrient N, P and K in steps: 1) per land unit within farm types \{equation (6.18)\}, 2) per land units summed over farm types \{equation (6.20)\}, 3) per farm type summed over the land units \{equation (6.22)\}, 4) summed over the farm types and over the land units \{equation (6.24)\}. At each of these steps, the depletion can be restricted. In the order of steps 1 to 4, these restrictions are equations (6.19), (6.21), (6.23) and (6.25), respectively. In detail:
* nutrient depletion balance per nutrient per farm type per soil type (kg year⁻¹);
\[ \sum_i \sum_j -h_{nfs} X_{fs} -N_{nfs} = 0 \quad \text{all} \; n, f, s \] (6.18)

* restriction on nutrient depletion per nutrient per farm type per soil type (kg year⁻¹);
\[ N_{nfs} \leq k_{nfs} \quad \text{all} \; n, f, s \] (6.19)

* nutrient depletion balances per nutrient per soil type (kg year⁻¹);
\[ \sum_f -N_{nfs} + N_{ns} = 0 \quad \text{all} \; n, s \] (6.20)

* restriction on nutrient depletion per nutrient per soil type (kg year⁻¹);
\[ N_{ns} \leq k_{ns} \quad \text{all} \; n, s \] (6.21)

* nutrient depletion balances per nutrient per farm type (kg year⁻¹);
\[ \sum_s -N_{nfs} + N_{nf} = 0 \quad \text{all} \; n, f \] (6.22)

* restriction on nutrient depletion per nutrient per farm type (kg year⁻¹);
\[ N_{nf} \leq k_{nf} \quad \text{all} \; n, f \] (6.23)

* nutrient depletion balances per nutrient (kg year⁻¹);
\[ \sum_f \sum_s -N_{nfs} + N_n = 0 \quad \text{all} \; n \] (6.24)

* restriction of sub-regional total nutrient depletion per nutrient (kg year⁻¹).
\[ N_n \leq k_n \quad \text{all} \; n \] (6.25)

The data on biocide use by the LUSTs (expressed as an index value per ha per year) is first aggregated at the farm type level (equation...
Chapter 6

(6.26); expressed as an index value per year} and restricted at that level \{equation (6.27)\}. Thereafter, the biocide use is summed over the farm types to provide a sub-regional total \{equation (6.28)\} and restricted to that level \{equation (6.29)\}. In detail:

* balances of biocide use per farm type (index value year\(^{-1}\));

\[
\sum_x \sum_f \sum_i u_{flt} \times x_{flt} - B_f = 0 \quad \text{all } f
\]  

(6.26)

* restriction on biocide use per farm type (index value year\(^{-1}\));

\[
B_f \leq v_f \quad \text{all } f
\]

(6.27)

* balance of total biocide use per year (index value year\(^{-1}\));

\[
\sum_f B_f - B = 0
\]

(6.28)

* restriction on sub-regional total biocide use (index value year\(^{-1}\)).

\[
B \leq v
\]

(6.29)

On the following pages the indices, variables and coefficients used are presented in Table 6.3, Table 6.4 and Table 6.5, respectively.
Table 6.3  Indices in REALM

<table>
<thead>
<tr>
<th>indices</th>
<th>description</th>
<th>elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>$j$</td>
<td>products</td>
<td>depends on selection(^1) of LUSTs</td>
</tr>
<tr>
<td>$i$</td>
<td>inputs</td>
<td>1(=)cost, 2(=)annlab(^2)</td>
</tr>
<tr>
<td>$f$</td>
<td>farm type</td>
<td>1(=)FT1, 2(=)FT2, 3(=)FT3, 4(=)FT4, 5(=)FT5(^3)</td>
</tr>
<tr>
<td>$s$</td>
<td>land units</td>
<td>depends on selection of LUSTs; at most SFP, SFW, SUW, FFP, FFW, FUW(^4)</td>
</tr>
<tr>
<td>$l$</td>
<td>land use types</td>
<td>depends on selection of LUSTs</td>
</tr>
<tr>
<td>$t$</td>
<td>technology</td>
<td>depends on selection of LUSTs</td>
</tr>
<tr>
<td>$o$</td>
<td>off-farm work</td>
<td>1(=)ofefarm, 2(=)plantat(^5)</td>
</tr>
<tr>
<td>$m$</td>
<td>months</td>
<td>1(=)jan, 2(=)feb, 3(=)mar, 4(=)apr, 5(=)may, 6(=)jun, 7(=)jul, 8(=)aug, 9(=)sep, 10(=)oct, 11(=)nov, 12(=)dec</td>
</tr>
<tr>
<td>$n$</td>
<td>nutrients</td>
<td>1(=)N, 2(=)P, 3(=)K(^6)</td>
</tr>
</tbody>
</table>

\(^1\) MODUS allows for a selection of LUSTs to be included in a connected linear programming model.

\(^2\) Element ‘1\(=\)cost’ refers to the annuity of current inputs use (materials and services, all measured in Colones) and element ‘2\(=\)annlab’ refers to the annuity of labour use (measured in hours).

\(^3\) Elements ‘1\(=\)FT1’ to ‘5\(=\)FT5’ stand for farm types 1 to 5.

\(^4\) The elements of index $s$, land units (soil types), are explained in Sections 6.4 and 6.5, and in Table 6.1, Section 6.2.

\(^5\) The element ‘1\(=\)ofefarm’ refers to family labour working off-farm on other farm types within the Neguev, while element ‘2\(=\)plantat’ refers to family labour working off-farm on plantations outside the Neguev; both measured in hours.

\(^6\) The three elements ‘1\(=\)N’, ‘2\(=\)P’ and ‘3\(=\)K’ of index $n$ stand for nitrogen, phosphorus and potassium, respectively.
Table 6.4 Variables in REALM

<table>
<thead>
<tr>
<th>variables$^1$</th>
<th>description</th>
<th>unit of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z$</td>
<td>value of objective function</td>
<td>$\ text{\ }$</td>
</tr>
<tr>
<td>$Q_j$</td>
<td>annuity production per product</td>
<td>kg year$^{-1}$; 'units' year$^{-1}$</td>
</tr>
<tr>
<td>$Q_{jf}$</td>
<td>annuity production per product per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$C_{i=1}$</td>
<td>annuity current input use</td>
<td>$\ text{\ }$</td>
</tr>
<tr>
<td>$C_{i=1,f}$</td>
<td>annuity current input use per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$C_{i=2}$</td>
<td>annuity labour use</td>
<td>hours year$^{-1}$</td>
</tr>
<tr>
<td>$C_{i=2,f}$</td>
<td>annuity labour use per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$X_{fht}$</td>
<td>LUSTs (land use per farm type per land unit per land use type per technology)</td>
<td>ha year$^{-1}$</td>
</tr>
<tr>
<td>$F_m$</td>
<td>on-farm work by family members per month</td>
<td>hours year$^{-1}$</td>
</tr>
<tr>
<td>$F_{mf}$</td>
<td>on-farm work by family members per month per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$H_m$</td>
<td>on-farm work by hired labour per month</td>
<td>do</td>
</tr>
<tr>
<td>$H_{mf}$</td>
<td>on-farm work by hired labour per month per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$O_{om}$</td>
<td>off-farm work by family members per work type per month</td>
<td>do</td>
</tr>
<tr>
<td>$O_{omf}$</td>
<td>off-farm work of family members per work type per month per farm type</td>
<td>do</td>
</tr>
<tr>
<td>$N_{gh}$</td>
<td>nutrients per nutrient per farm type per land unit</td>
<td>kg year$^{-1}$</td>
</tr>
<tr>
<td>$N_n$</td>
<td>nutrients per nutrient per land unit</td>
<td>kg year$^{-1}$</td>
</tr>
<tr>
<td>$N_{f}$</td>
<td>nutrients per nutrient per farm type</td>
<td>kg year$^{-1}$</td>
</tr>
<tr>
<td>$N$</td>
<td>nutrients per nutrient</td>
<td>kg year$^{-1}$</td>
</tr>
<tr>
<td>$B_f$</td>
<td>biocides use per farm type</td>
<td>index value year$^{-1}$</td>
</tr>
<tr>
<td>$B$</td>
<td>biocides use</td>
<td>do</td>
</tr>
</tbody>
</table>

$^1$ All variables in the model are continuous and larger than, or equal to, zero, except $N_{gh}$, $N_n$, $N_f$ and $N$ which are 'free' continuous variables (larger than minus infinity). Furthermore, $\ text{\ }$ is Colón, the currency unit of Costa Rica.
### Table 6.5 Coefficients in REALM

<table>
<thead>
<tr>
<th>coefficients</th>
<th>description</th>
<th>units of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_j )</td>
<td>product price per product (OBJ)(^1)</td>
<td>( \text{$ kg}^{-1}; \text{$ 'unit'}^{-1} )</td>
</tr>
<tr>
<td>( p_{i=1} )</td>
<td>inputs costs (OBJ)</td>
<td>( \text{$ 'unit'}^{-1} )</td>
</tr>
<tr>
<td>( p_{i=2} )</td>
<td>reservation wage (OBJ)</td>
<td>( \text{$ hour}^{-1} )</td>
</tr>
<tr>
<td>( w_m )</td>
<td>hired labour wage per month (OBJ)</td>
<td>( \text{$ hour}^{-1} )</td>
</tr>
<tr>
<td>( z_{om} )</td>
<td>off-farm work wages per work type per month (OBJ)</td>
<td>( \text{$ hour}^{-1} )</td>
</tr>
<tr>
<td>( y_{filt} )</td>
<td>annuity yield of a LUST(^2)</td>
<td>( \text{kg ha}^{-1}; \text{ 'units' ha}^{-1} )</td>
</tr>
<tr>
<td>( c_{i=1,filt} )</td>
<td>annuity input costs of a LUST</td>
<td>( \text{$ ha}^{-1} )</td>
</tr>
<tr>
<td>( c_{i=2,filt} )</td>
<td>annuity labour use of a LUST</td>
<td>( \text{hours ha}^{-1} )</td>
</tr>
<tr>
<td>( a_{filtm} )</td>
<td>average land use of a LUST per month</td>
<td>( \text{ha ha}^{-1} )</td>
</tr>
<tr>
<td>( b_{filtm} )</td>
<td>land availability per farm type per land unit per month (RHS)(^3)</td>
<td>( \text{ha year}^{-1} )</td>
</tr>
<tr>
<td>( e_{filtm} )</td>
<td>average labour use of a LUST per month</td>
<td>( \text{hours ha}^{-1} )</td>
</tr>
<tr>
<td>( g_{filtm} )</td>
<td>household labour availability per farm type per month (RHS)</td>
<td>( \text{hours year}^{-1} )</td>
</tr>
<tr>
<td>( g_{f} )</td>
<td>household labour availability per farm type (RHS)</td>
<td>( \text{hours year}^{-1} )</td>
</tr>
<tr>
<td>( p_{o=2} )</td>
<td>plantation employment availability (RHS)</td>
<td>( \text{hours year}^{-1} )</td>
</tr>
<tr>
<td>( h_{refilt} )</td>
<td>average nutrient loss or gain of a LUST</td>
<td>( \text{kg ha}^{-1} )</td>
</tr>
<tr>
<td>( k_{ref} )</td>
<td>permissible nutrient loss or gain per nutrient per farm type per land unit (RHS)</td>
<td>( \text{kg year}^{-1} )</td>
</tr>
<tr>
<td>( k_{ref} )</td>
<td>permissible nutrient loss or gain per nutrient per farm type (RHS)</td>
<td>( \text{kg year}^{-1} )</td>
</tr>
<tr>
<td>( k_{n} )</td>
<td>permissible nutrient loss or gain per nutrient (RHS)</td>
<td>( \text{kg year}^{-1} )</td>
</tr>
<tr>
<td>( u_{filt} )</td>
<td>average biocide index value of a LUST</td>
<td>( \text{index value ha}^{-1} )</td>
</tr>
<tr>
<td>( v_{f} )</td>
<td>permissible biocide index value per farm type (RHS)</td>
<td>( \text{index value year}^{-1} )</td>
</tr>
<tr>
<td>( v )</td>
<td>permissible biocide index value (RHS)</td>
<td>( \text{index value year}^{-1} )</td>
</tr>
</tbody>
</table>

\(^1\) OBJ: objective function coefficient
\(^2\) LUST: variable \( X_{filt} \) see Table 6.4
\(^3\) RHS: right hand side coefficient
7 LAND USE SCENARIOS IN THE NEGUEV

7.1 Scenarios in land use analysis

In Chapter 6 the land use model REALM was presented. The purpose of this model is to study the effects of changes in factors that influence land use. The analyses are in the first place related to the use of land itself (LUSTs) and in the second place to the consequences of land use for incomes, employment and environmental parameters. As a model is an abstraction of reality, a sound approach is either to assess these effects in relation to a standard solution of the model (‘base’ case), or to compare one solution with another. Only in one instance, is an effort made to assess the effects as estimated by the model and compare them with reality, as in general such a comparison would not be useful given the limitations of the present model. Each different situation with regard to a (variation in a) factor having a bearing on land use, can be called a scenario, or a variant of a scenario. In the context of land use studies, scenarios are defined as "Possible trends in land use determinants and/or policy measures." (Alfaro et al., 1994). A number of factors influencing land use can be envisaged, for example population growth, wages, discount rates, relative product prices, and natural events like flooding, volcanic eruptions and earthquakes. With regard to those factors assumptions can be made as to how they will occur or change in the future. Each of these assumptions corresponds to a scenario or a variant thereof. Table 7.1 provides an overview of the eight different land use scenarios presented in this chapter.

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117 This chapter is largely based on Schipper et al. (1995a).

118 The more so as for each land use system the model can choose between present and potential technologies, while in the actual situation as observed in 1991 farmers could only choose from actually available technologies. Therefore, in the present study the actual land use as observed in 1991 is only compared with the land use according to the present land use systems (see below).
Table 7.1  An overview of the scenarios

Scenarios and their variants:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name base scenario</td>
<td>Constraints: no restriction on biocide use and nutrient depletion</td>
</tr>
<tr>
<td>Data</td>
<td>actual and potential LUSTs</td>
</tr>
<tr>
<td>Results</td>
<td>optimal land use under assumed base conditions</td>
</tr>
<tr>
<td>Name present land use systems</td>
<td>Constraints: as in base scenario</td>
</tr>
<tr>
<td>Data</td>
<td>only present LUSTs (based on 1991/1992 Neguev farm survey)</td>
</tr>
<tr>
<td>Results</td>
<td>optimal land use under assumed present conditions</td>
</tr>
<tr>
<td>Name biocide reduction</td>
<td>Constraints: biocide use index; three variants: 50% of base scenario, at Neguev level, at farm type level, and at farm type level proportional to the area (ha) of each farm type, respectively</td>
</tr>
<tr>
<td>Data</td>
<td>as in base scenario</td>
</tr>
<tr>
<td>Results</td>
<td>effects of restricting biocide use on land use</td>
</tr>
<tr>
<td>Name price of biocide</td>
<td>Constraints: as in base scenario</td>
</tr>
<tr>
<td>Data</td>
<td>doubling of biocide prices</td>
</tr>
<tr>
<td>Results</td>
<td>relation biocide price (as a possible incentive) and biocide use</td>
</tr>
<tr>
<td>Name soil nutrient depletion</td>
<td>Constraints: soil nutrient depletion at the level of land units within farm types</td>
</tr>
<tr>
<td>Data</td>
<td>as in base scenario</td>
</tr>
<tr>
<td>Results</td>
<td>effects of restricting soil nutrient depletion on land use</td>
</tr>
<tr>
<td>Name price of palm heart</td>
<td>Constraints: as in base scenario</td>
</tr>
<tr>
<td>Data</td>
<td>price reductions of palm heart of 5 to 50% (in steps of 5%)</td>
</tr>
<tr>
<td>Results</td>
<td>relation between price of palm heart and its production</td>
</tr>
<tr>
<td>Name price of labour</td>
<td>Constraints: as in base scenario</td>
</tr>
<tr>
<td>Data</td>
<td>changes in labour costs from -25 to +25 % (in steps of 5%)</td>
</tr>
<tr>
<td>Results</td>
<td>relation between labour costs and land use</td>
</tr>
<tr>
<td>Name discount rate</td>
<td>Constraints: as in base scenario</td>
</tr>
<tr>
<td>Data</td>
<td>separate calculations with discount rates of 0, 3, 5, 10 (=base), 15 and 20%</td>
</tr>
<tr>
<td>Results</td>
<td>relation between discount rate and land use</td>
</tr>
</tbody>
</table>
Three scenarios related to land use determining factors are discussed: *price of palm heart, price of labour* and *discount rate* scenario. Possible policy measures and their influence on land use will be studied in three alternative scenarios: *biocide reduction, price of biocide* and *soil nutrient depletion* scenario. All the scenarios are compared with a *base* scenario, in which 1991 prices are used and no restriction is placed on either biocide use or soil nutrient depletion. In this base scenario the model can choose from all possible technologies in all land use systems.

Why these scenarios? A major concern of this study is the development of a methodology for land use analysis in order to study possibilities for improving farm incomes, while at the same time using land in a sustainable way. In the actual case study two sustainability indicators are relevant: biocide use and soil nutrient depletion. Furthermore, it is thought possible to influence farm household decision making via policy interventions. Environmental policies can be implemented through regulations or via market incentives. With regard to the biocide use both options are studied. Biocide use might be restricted by prohibiting use over a certain maximum level. In the absence of health or environmental standards, this maximum could be related to the use in a base year (*biocide reduction* scenario). On the other hand, biocide use might be reduced by increasing biocide prices, for example through a sales tax (*price of biocide* scenario). As market interventions for reducing the soil nutrient depletion are more difficult to envisage, only a regulatory policy is analysed in the *soil nutrient depletion* scenario.

The socio-economic environment of the farm households is not static. For example, in a growing economy labour productivity, both inside and outside agriculture, can be expected to rise. The population in the Atlantic Zone of Costa Rica is growing due to natural growth and immigration, but this is not expected to have much influence on land use in the Neguev. On the contrary, people migrate out from the Neguev as its conditions (soil fertility, employment opportunities) are not promising for agriculture. Favourable outside employment opportunities and an increasing labour productivity will induce rising wages. This is expected to change land use towards labour-saving crops and technologies. To be complete, the effects of decreasing wages are also analysed. These opposing trends in wages are investigated in the *price of labour* scenario.

Relative prices of agricultural products are an important factor in deciding upon land use. Of course, the relative prices of all products could change, and have done so in the past. However, only a fall in the price of palm heart is analysed, as palm heart is an economically attractive crop that is selected extensively in nearly all solutions of the
model. In reality, the area under palm heart cultivation is expanding too. There are reasons to believe that expanding the area of palm heart might lead to an excess supply of this product, resulting in a decrease in its price; hence a *price of palm heart* scenario, analysing the effects of such a decrease.

As most of the LUSTs concern (semi-)perennial land uses, benefits and costs in different years are discounted, aggregated into their present value and finally converted to an annuity (Section 6.3). Values thus obtained depend, of course, on the discount rate. In order to investigate the sensitivity of the results for different discount rates, a *discount rate* scenario was studied.

In contrast to scenarios in which farms can select from LUSTs with present technologies and from LUSTs with potential technologies, *in reality* - Neguev, 1991 - farms operate on the basis of actually available technologies. Therefore, a *present land use systems* scenario, in which the model can select only the LUSTs with technologies defined on the basis of the 1991/92 farm survey (Jansen & Schipper, 1995; Appendix 4), was calculated as well. Such a scenario serves two purposes. First, it allows for a - limited - comparison with *actual* land use in the Neguev, derived from other sources (Section 6.2). Secondly, by comparing the *present land use systems* scenario with the *base* scenario, a measure of the magnitude and impact of possible changes due to technical innovations is provided.

The comparison of use of land in the *present land use systems* scenario with the *actual* 1991 land use brings to the fore the issue of validation of the model. Although a number of partial tests for validating linear programming models of agricultural sectors are proposed, no agreed method exists for determining the overall validity of such a model. Therefore, trying to reproduce the situation in a base year as close as possible is usually resorted to (Hazell & Norton, 1986: 266-274). First it should be checked whether the input and output coefficients and factor availability are representative for the situation in the base year. Then, if the results of the model with regard to some major variables (e.g. land use, production, income, land rent, employment) are close to the base year values, one can have more confidence in the model. However, in the present case, representative data exist for land use only (Table 6.1), while data on production, income and employment merely exist from a limited number of case studies (Section 6.2; Appendix 4).

In Section 7.3, land use according to the *present land use systems* scenario is compared with the *actual* land use. The fit is rather poor, for which several reasons can be put forward. This outcome notwithstanding,
comparison among different scenarios is still valuable for studying the consequences of certain changes in land use determining factors and/or policies through the analysis of different scenarios. After outlining the results of the base scenario in the next section, such a comparison is outlined in the remaining sections of this chapter.

7.2 Base scenario

In the base scenario, each of the five farm types in the model can choose from 105 LUSTs (based on six land units, eight land use types, and, depending on the land unit / land use type combination, a number of technologies; Jansen & Schipper, 1995). No restriction is placed on the use of biocides and on the depletion of soil nutrients N, P and K. Wages are different for each category of paid work, that is hired labour, work on other farms within the Neguev and work on a plantation outside the Neguev\(^{119}\). For on-farm work by members of a household a 'reservation' wage of two-thirds of the wage rate for hired labour is assumed. This assumption is arbitrary, not based on a research finding. However, for a neat functioning of the model such a wage has to be lower than the lowest wage rate for working off-farm. The sensitivity of the model for different assumptions regarding the reservation wage will be examined below. The rationale for a 'reservation' wage is that people are not willing to work on their own farms if they cannot earn a certain minimum return (Section 5.3, footnote 93). By imposing a reservation wage, the linear programming model will not select an activity with a return to family labour lower than the reservation wage, unless forced to by other constraints, for example, a minimum self-sufficiency requirement regarding basic foods. Alternatively, it can be said that a

\(^{119}\) The wage rate for hired labour is 100 Colones per hour, which is according to the observed 1991 wage rate in the Neguev. Working off-farm on other farms within the Neguev pays 90 Colones per hour (the hired wage rate minus assumed transaction costs), while working on a plantation outside the Neguev has an hourly wage of 188 Colones.

For use in REALM, these wage rates are multiplied by \(1 + \frac{(\text{discount rate/100})}{100}\) for the following reason. As explained in Section 6.3, yearly production, input and total on-farm labour use variables are summed to present values over the life span of the LUSTs and subsequently transformed to annuities, using the discount rate. However, discounting was done to year 1, not to year 0. As the monthly labour uses are not discounted, but calculated as averages over the years, the wages applied to these monthly uses are compounded to year 1, to make the labour activities more commensurable with the land use activities.
reservation wage reflects the preference for leisure of a household. The discount rate is assumed to be 10%. All input and output prices are 1991 farm-gate prices.

The results of the base scenario will be presented under four headings: farm production economics, income structure and employment; land use; soil nutrient depletion; and biocide use. Each time the outcome will be presented both for the sub-region Neguev as well as per farm type. The first shows the average for all farm types, while the second provides an understanding of the differences between farm types. After presenting these results of the base scenario, the effect of distinguishing five farm types on the magnitude of the aggregation bias will be examined, followed by an analysis of the sensitivity of the model’s results for different assumptions regarding the reservation wage.

Farm production economics, income structure and employment

The value of the objective function, or the economic surplus, in the base scenario is Colones \(418 \times 10^6\) year\(^{-1}\) (Table 7.8), equivalent to US$ 3.4 million; about US$ 11,000 per farm per year\(^{120}\). The objective function value differs per farm type, which is reflected in the differences with regard to the production economics results (Table 7.2). For example, compare between farm types, the gross margin or the return to land, own capital and management of the farm. These results are related to the available land resources per farm (Table 6.2, Section 6.4, reproduced in Table 7.2). Only land-related resources are relevant here, as each farm type is assumed to have 2.0 labour-year labour resources available. Farm type 1 is the worst endowed farm type, which is reflected in the worst farm production economics performance. Because farm type 2 is largest in area, its farm performance is the best. Farm type 3 is somewhat better endowed than an average farm, with corresponding performance. Farms of type 4 are qualitatively best endowed. Their farm performance is also the best after that of the ‘large’ farm type 2. Finally, farms of type 5, the largest group, have resources that are less than average, while the same applies to its performance. Thus, as is inherent to a linear programming model with an economic objective function, there is a close relation between the quantity and quality of the land resources of a farm and its farm economic performance.

\(^{120}\) In 1991, on average, 1 US$ = 122 Colones.
Table 7.2 Land related resources and production economics results per farm type: base scenario

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of farms</td>
<td>33</td>
<td>4</td>
<td>46</td>
<td>35</td>
<td>189</td>
<td></td>
</tr>
<tr>
<td>Average area (ha)</td>
<td>15.7</td>
<td>32.1</td>
<td>13.5</td>
<td>14.1</td>
<td>13.1</td>
<td>13.8</td>
</tr>
<tr>
<td>SFP&lt;sup&gt;1&lt;/sup&gt; soils (%)</td>
<td>60</td>
<td>12</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>SFW&lt;sup&gt;2&lt;/sup&gt; soils (%)</td>
<td>12</td>
<td>10</td>
<td>52</td>
<td>91</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>SUW&lt;sup&gt;3&lt;/sup&gt; soils (%)</td>
<td>28</td>
<td>78</td>
<td>41</td>
<td>6</td>
<td>88</td>
<td>64</td>
</tr>
<tr>
<td>Value of production&lt;sup&gt;4&lt;/sup&gt;</td>
<td>879</td>
<td>2727</td>
<td>1531</td>
<td>2106</td>
<td>1284</td>
<td>1390</td>
</tr>
<tr>
<td>Input costs&lt;sup&gt;5&lt;/sup&gt;</td>
<td>89</td>
<td>181</td>
<td>123</td>
<td>118</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Hired labour&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0</td>
<td>92</td>
<td>8</td>
<td>51</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Gross margin&lt;sup&gt;7&lt;/sup&gt;</td>
<td>790</td>
<td>2454</td>
<td>1400</td>
<td>1938</td>
<td>1169</td>
<td>1267</td>
</tr>
<tr>
<td>Own labour&lt;sup&gt;8&lt;/sup&gt;</td>
<td>82</td>
<td>265</td>
<td>149</td>
<td>215</td>
<td>126</td>
<td>136</td>
</tr>
<tr>
<td>Return to land, own capital &amp; management of farm&lt;sup&gt;9&lt;/sup&gt;</td>
<td>708</td>
<td>2189</td>
<td>1252</td>
<td>1723</td>
<td>1043</td>
<td>1131</td>
</tr>
</tbody>
</table>

<sup>1</sup> SFP: Fertile poorly-drained soil.
<sup>2</sup> SFW: Fertile well-drained soil.
<sup>3</sup> SUW: Unfertile well-drained soil.
<sup>4</sup> Value of production: physical output, valued at farm gate prices (Colones 10<sup>3</sup> year<sup>-1</sup>).
<sup>5</sup> Input costs: costs for current input goods (e.g. seeds, fertilizers, biocides) and capital services (e.g. use of machete, knapsack sprayer); in case of own capital goods, capital services include operation costs and depreciation per hour of use; in case of hired goods, capital services are expressed as a rental rate per hour (Colones 10<sup>3</sup> year<sup>-1</sup>).
<sup>6</sup> Hired labour: costs for hired labour (Colones 10<sup>3</sup> year<sup>-1</sup>).
<sup>7</sup> Gross margin = Value of production - Input costs - Hired labour (Colones 10<sup>3</sup> year<sup>-1</sup>).
<sup>8</sup> Own labour: valuation of on-farm household labour at a reservation wage (Colones 10<sup>3</sup> year<sup>-1</sup>)
<sup>9</sup> Return to land, own capital and management of farm = Gross margin - Own labour (Colones 10<sup>3</sup> year<sup>-1</sup>).
The performance of each farm type is also reflected in the corresponding income structure (Table 7.3) and labour use (Table 7.4). Farm types 1 and 5 compensate relatively low returns for farming activities by working more off-farm, both on other farms within the Neguev, as well as on plantations outside the Neguev. Family members of the remaining farm types do not work on other farm types and also work less on plantations\textsuperscript{121}.

Table 7.3 Income structure per farm type: base scenario (Colomes 10\textsuperscript{3} year\textsuperscript{-1})

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross margin</td>
<td>790</td>
<td>2454</td>
<td>1400</td>
<td>1938</td>
<td>1169</td>
<td>1267</td>
</tr>
<tr>
<td>Work on other farms\textsuperscript{1}</td>
<td>31</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Plantation work\textsuperscript{2}</td>
<td>308</td>
<td>63</td>
<td>193</td>
<td>70</td>
<td>246</td>
<td>222</td>
</tr>
<tr>
<td>Farm household income\textsuperscript{3}</td>
<td>1130</td>
<td>2516</td>
<td>1596</td>
<td>2007</td>
<td>1421</td>
<td>1496</td>
</tr>
<tr>
<td>Own labour</td>
<td>82</td>
<td>265</td>
<td>149</td>
<td>215</td>
<td>126</td>
<td>136</td>
</tr>
<tr>
<td>Economic surplus\textsuperscript{4}</td>
<td>1048</td>
<td>2251</td>
<td>1446</td>
<td>1792</td>
<td>1295</td>
<td>1360</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Work on other farms: remuneration for work on other farms within Neguev.

\textsuperscript{2} Plantation work: remuneration for work on plantations outside Neguev.

\textsuperscript{3} Farm household income = Gross margin + Work on other farms + Plantation work.

\textsuperscript{4} Economic surplus = Farm household income - Own labour; it represents the returns to land, own capital and management of farm, and to labour employed off-farm; calculated as a balance, it is an indicator of the postulated objective of the farm households. It coincides with the objective function of the linear programming model in all scenarios.

\textsuperscript{121} A person can work on a banana plantation for periods of three months only, with three months compulsory waiting before resuming work for the same banana company (Section 6.5, page 136). In the present form of REALM, this fact has been taken into account by limiting the amount of plantation work to half of the - aggregated - available household labour in each month. This is a reasonable first approximation, but does not take into account that the employment contracts are for three consecutive months (Norton, 1995b: 3). If this feature is built into the model the value of the objective function would be nearly 3\% lower than in the base scenario, while 11\% more plantation work would be done. The complication that once somebody starts to work for a plantation (s)he has to continue for a period of three months, is ignored in the remainder of the study.
Table 7.4  Labour use per farm type: base scenario (days year⁻¹)

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own labour¹</td>
<td>145</td>
<td>334</td>
<td>255</td>
<td>329</td>
<td>215</td>
<td>228</td>
</tr>
<tr>
<td>Hired labour²</td>
<td>0</td>
<td>105</td>
<td>9</td>
<td>58</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Work on other farms³</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Plantation work⁴</td>
<td>196</td>
<td>37</td>
<td>117</td>
<td>42</td>
<td>147</td>
<td>134</td>
</tr>
</tbody>
</table>

¹ Own labour: household labour working on-farm.
² Hired labour: labour from other farms within Neguev.
³ Work on other farms: household labour working on other farms within Neguev.
⁴ Plantation work: household labour working on plantations outside Neguev.

Land use

The creation of income and work in the Neguev is largely based on the use of land by different farm types. As Table 7.5 shows, land units with well-drained, fertile and unfertile soils (soil types SFW & SUW, respectively) are mainly used for palm heart (2,676 ha), followed by cassava (254 ha) and tree plantations (29 ha). Land units with fertile poorly-drained soils (soil type SFP, in total 422 ha) are not used at all. The forest land units are logged on a sustainable basis.

It is important to note that the outcome of the base scenario is heavily biased towards palm heart: 79% of the available area should be planted with palm heart. The optimal solution selects a zero fertilizer technology, yielding about 80% of the potential production of 10,000 palm hearts ha⁻¹ year⁻¹ on the fertile well-drained soils (SFP), three years after planting (5,000 plants ha⁻¹). On the unfertile well-drained soils (SUW) this technology yields about 5,000 units ha⁻¹ year⁻¹. Given relative prices, inputs and labour use, this appears to be an attractive technology for

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¹²² Incorporating the feature of working three consecutive months on plantations leads to minor changes in land use, because less labour for on-farm work is available as more plantation work is done. For the Neguev as a whole, slightly less palm heart (-1%), considerably less cassava (-37%), but much more tree plantations (+221%) would be cultivated.
palm heart. Moreover, apart from the technology, palm heart as such is an attractive crop, as is confirmed in other studies\textsuperscript{123}. Furthermore, the results of other scenarios, often using alternative technologies, indicate that palm heart is nearly always the most important crop.

Although the area planted with palm heart has been steadily increasing since 1987, the actual 1991 area under palm heart (about 140 ha, Table 6.1, Section 6.2) is significantly less than the area as calculated by the base scenario. Therefore, the base scenario results can be interpreted as an indication that in the future more palm heart could be planted\textsuperscript{124}.

A main bottleneck for production increases could be the market for palm hearts. Palm heart is a luxury product with a relatively small domestic and international market, though, given rising incomes, both will grow. The main importers are France and the USA. However, the international market is crowded by competitors, especially Brazil and Colombia\textsuperscript{125}. In 1989 the area used for palm heart production in Costa Rica was about 2,000 ha, while the area in 1994 was about 3,900 ha (van Tilburg \textit{et al.}, 1995: 25). Thus, after a near doubling of the area between 1989 and 1994, an area of 2,676 ha with palm heart in the Neguev, about 2,500 more than the actual area, would increase the national area by another 60%. Such an area expansion might lead to decreasing prices. However, considerable increases in volume and value of exports of Costa Rica from 1981 to 1992 did not result in any real price decrease. On the contrary, in value terms palm heart exports rose more than in volume terms\textsuperscript{126}. In order to evaluate the sensitivity of the model for price changes, the problem of a possible future price reduction is addressed in the \textit{price of palm heart} scenario.

\textsuperscript{123} E.g. de Haan & Waaijenberg (1992: 90-91) and Waaijenberg (1990: 45).

\textsuperscript{124} Cursory field observations during 1993 and 1994 suggest that farms were still planting new palm heart. However, preliminary results of a survey in the beginning of 1996 among 47 farms, out of the 53 farms interviewed in the 1987 baseline survey (Appendix 3), indicate that the palm heart area in the Neguev can be estimated at about 150 ha (Kuiper, 1996).

\textsuperscript{125} Urpi \textit{et al.}, 1991; Ruiz, 1993; van Tilburg \textit{et al}, 1995: 74-77.

\textsuperscript{126} Using linear regression to smooth annual fluctuations, it is estimated that between 1982 and 1987, export volume increased annually by 43\% and real export value (in US$, deflated using the US manufactures export price index) by 63\%. Between 1987 and 1992, export volume increased annually by 33\% and real export value by 39\%. 
Table 7.5  Land use\(^1\) per farm type: base scenario (ha year\(^{-1}\))

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
<th>Neguev total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logged forest on FFP(^2)</td>
<td>2.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2</td>
<td>0.4</td>
<td>118</td>
</tr>
<tr>
<td>Logged forest on FFW(^2)</td>
<td>0.5</td>
<td>0.1</td>
<td>2.1</td>
<td>1.2</td>
<td>0.4</td>
<td>0.7</td>
<td>223</td>
</tr>
<tr>
<td>Logged forest on FUW(^2)</td>
<td>1.0</td>
<td>3.4</td>
<td>1.3</td>
<td>0.1</td>
<td>2.2</td>
<td>1.7</td>
<td>515</td>
</tr>
<tr>
<td>Palm heart on SFW(^2)</td>
<td>1.4</td>
<td>0.6</td>
<td>4.9</td>
<td>11.1</td>
<td>0.4</td>
<td>2.4</td>
<td>732</td>
</tr>
<tr>
<td>Cassava on SFW(^2)</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Tree plantation on SFW(^2)</td>
<td>0.0</td>
<td>2.5</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>0.1</td>
<td>29</td>
</tr>
<tr>
<td>Palm heart on SUW(^2)</td>
<td>2.5</td>
<td>21.4</td>
<td>3.5</td>
<td>0.2</td>
<td>8.5</td>
<td>6.3</td>
<td>1944</td>
</tr>
<tr>
<td>Cassava on SUW(^2)</td>
<td>1.0</td>
<td>0.2</td>
<td>0.7</td>
<td>0.4</td>
<td>0.9</td>
<td>0.8</td>
<td>254</td>
</tr>
<tr>
<td>Available area</td>
<td>15.7</td>
<td>32.1</td>
<td>13.5</td>
<td>14.1</td>
<td>13.1</td>
<td>13.8</td>
<td>4236</td>
</tr>
</tbody>
</table>

\(^1\) Excluding SFP\(^2\) area of each farm type (422 ha in total), as it is not cultivated in the base scenario.

\(^2\) Land unit codes:
- SFP: Fertile poorly-drained soil
- FFP: Fertile poorly-drained soil, with a forest cover at present
- SFW: Fertile well-drained soil
- FFW: Fertile well-drained soil, with a forest cover at present
- SUW: Unfertile well-drained soil
- FUW: Unfertile well-drained soil, with a forest cover at present

Soil nutrient depletion

Soil nutrient balances (for N, P and K) are calculated by separate assessment of nutrient inputs (mineral and organic fertiliser, wet deposition and N-fixation) and nutrient outputs (production, stover, denitrification and leaching) with an adapted version of the NUTBAL nutrient balance model (Stoorvogel, 1993).

Soil nutrient depletion in the base scenario is shown in Table 7.6. The average annual soil depletion for N is 16.6 kg ha\(^{-1}\) year\(^{-1}\) and for K is kg ha\(^{-1}\) year\(^{-1}\), while 2.4 kg ha\(^{-1}\) year\(^{-1}\) of P is added to the soil. Soil nutrient depletion differs per farm type and soil type, depending on the land use. The consequences of a restriction on the depletion of nutrients at the level
of land units within each farm type are examined in the *soil nutrient depletion* scenario.

Table 7.6  
Soil nutrient depletion per farm type: *base* scenario (kg ha\(^{-1}\) year\(^{-1}\))

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>-7.1</td>
<td>-16.9</td>
<td>-16.8</td>
<td>-22.1</td>
<td>-17.4</td>
<td>-16.6</td>
</tr>
<tr>
<td>P</td>
<td>2.6</td>
<td>0.3</td>
<td>2.1</td>
<td>0.8</td>
<td>2.8</td>
<td>2.4</td>
</tr>
<tr>
<td>K</td>
<td>-6.0</td>
<td>-11.7</td>
<td>-13.4</td>
<td>-18.2</td>
<td>-12.8</td>
<td>-12.7</td>
</tr>
</tbody>
</table>

**Biocide use**

The effect of biocide use on the environment is assessed by means of a biocide use index. This is an indicator for the amount of active ingredients, their half life time and toxicity (Jansen *et al.*, 1995). The indicator is first calculated for the sum of the biocide use per LUST (per ha) and then aggregated for the total land use.

The value of the biocide use index amounts to 30 ha\(^{-1}\) year\(^{-1}\) for the whole Neguev. There are large differences between the farm types (Table 7.7). The consequences of imposing a limitation on the use of biocides are reviewed in the *biocide reduction* scenario.

Table 7.7  
Biocide use index per farm type: *base* scenario (index value ha\(^{-1}\) year\(^{-1}\))

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biocide use index</td>
<td>14</td>
<td>30</td>
<td>29</td>
<td>36</td>
<td>32</td>
<td>30</td>
</tr>
</tbody>
</table>

**Aggregation bias**

In order to diminish the aggregation bias (normally in an upward direction), it is important to group farms that are similar. As all farms
have access to the same land use systems and technologies, their sub-
matrices with input and output coefficients are equal, as well as their
(expectations about) per unit returns. Farm types only differ in the
relative availability of the different land units and labour. In that case the
aggregation bias is likely to be small (Section 5.1, footnote 77), in
particular if one of the resources can be exchanged among farm types.
This is the case for household labour which can work on other farm types
as hired labour. In doing so, differences in land/labour ratios become
smaller. Of course, labour exchange involves a transaction cost. In the
present model, the transaction cost per hour is the difference between the
wage for hired labour and the wage for off-farm work within the
Neguev.

The situation with regard to farm types and the exchange of labour
between them can be compared with factor mobility between countries. If
factor mobility is possible, for example in the case of capital, the factor
will move to a country where it is in relatively short supply and can be
used in a profitable way, given production possibilities and taking into
account transaction costs. If such mobility is not possible or restricted,
for example in case of labour, trade in a product is likely to occur on the
basis of the comparative advantages of each country.

In order to show the extent of the aggregation bias, the five farm
types were collapsed into one large farm, the Neguev itself. To this
effect, the resources of all farm types were simply added up. Compared
to the base solution the upward bias in terms of the objective function is
very small, just 0.06%. The difference mainly consists of the
disappearance of the transaction costs in the aggregated model.
Nevertheless, the aggregated model does give slightly different values for
a number of variables. For example, the production value increases
somewhat as the net result of cultivating more teak and melina trees but
less palm heart and cassava. Costs for inputs and household labour (via
the reservation wage) are somewhat higher, while a fraction less work is
done on plantations. However, the aggregated results hide interesting
changes in activities. For example, less palm heart is cultivated, but this
results from more palm heart on fertile soils (SFW) and less palm heart
on unfertile soils (SUW). In other words, the comparative advantage of
SUW soils for palm heart (see price of palm heart scenario, Section 7.7)
has less weight.
With regard to the overall objective function and the use of land, disaggregating the model into farm types is clearly not worthwhile. However, this results from the specific properties of the model, in particular the uniform input, output, and objective function coefficients for each farm type, and the labour exchange between farm types. Whether the aggregation bias is also small when there are more farm type specific constraints, will be examined in the biocide reduction scenario.

Sensitivity for assumed reservation wage

An explanation was offered above for why a reservation wage for household on-farm labour was assumed. It was fixed at two-thirds of the - uncompounded - hired labour wage rate. The highest possible wage for the reservation wage would be the - uncompounded - wage for off-farm employment within Neguev, while the lowest would be zero per hour. The latter means effectively abandoning the idea of a reservation wage. From the optimal solution of the base scenario it can be derived that this solution will not change, keeping the reservation wage between an upper limit nearly double the hired labour wage rate and a lower limit of nearly half that wage. This implies that increasing the reservation wage to the wage for off-farm work within the Neguev would not affect the solution, whereas lowering it to zero would. Indeed, when using a reservation wage equal to the wage for off-farm work within the Neguev, the value of the objective function decreases by about 4% compared to the objective function in the base solution. The difference is completely made up of the higher reservation wage, as the number of hours worked is not changed.

Lowering the reservation wage to zero per hour, the objective function increases by 10% compared to the base solution. Most of the difference (98%) consists of ‘not-paying’ the reservation wage. Nevertheless, in the case of a zero reservation wage the value of a number of variables changes compared with the base solution. As can be expected, more on-farm work is done by household labour, while less labour is hired and, consequently, less off-farm work is done, including less work on

127 On the other hand, disaggregating the model into farm types does provide insight into differences between farm types (e.g. incomes, employment, land use, biocide use and soil nutrient depletion).

128 Indeed, if in the base solution the ‘payment’ of the reservation wage is added to the value of the objective function, this sum is very close to the objective function in the case of a zero reservation wage.
plantations. Land use also changes. Now, it becomes worthwhile to use the fertile poorly-drained soils (SFP), in particular for pasture with cattle (372 ha), but also for cassava (50 ha). There are some minor changes with regard to the other land units too. The land use changes result in a higher value of production with less costs for inputs, while somewhat more N (5%) and K (7%) are depleted, more P (9%) is added, and more biocides (7%) are used. The rather restricted reaction of the model to changes of the reservation wage compares well with similar reactions to such changes in other linear programming models of agricultural sectors, e.g. in Northeast Brazil (Kutcher & Scandizzo, 1981: 159-160) and Mexico (Duloy & Norton, 1973b).

Table 7.8 Value of objective function: base scenario versus present land use systems and sustainability policy related scenarios (Colones 10$^6$ year$^{-1}$)

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>35</td>
<td>9</td>
<td>66</td>
<td>63</td>
<td>245</td>
<td>418</td>
</tr>
<tr>
<td>Present land use systems</td>
<td>23</td>
<td>9</td>
<td>41</td>
<td>27</td>
<td>218</td>
<td>319</td>
</tr>
<tr>
<td>Biocide a (50% reduction Neguev level)</td>
<td>35</td>
<td>9</td>
<td>66</td>
<td>63</td>
<td>241</td>
<td>414</td>
</tr>
<tr>
<td>Biocide b (50% reduction per farm type)</td>
<td>35</td>
<td>9</td>
<td>66</td>
<td>62</td>
<td>242</td>
<td>414</td>
</tr>
<tr>
<td>Biocide c (50% reduction per ha)</td>
<td>35</td>
<td>9</td>
<td>66</td>
<td>62</td>
<td>242</td>
<td>414</td>
</tr>
<tr>
<td>Price of biocide</td>
<td>34</td>
<td>9</td>
<td>66</td>
<td>62</td>
<td>241</td>
<td>412</td>
</tr>
<tr>
<td>Soil nutrient depletion</td>
<td>34</td>
<td>9</td>
<td>64</td>
<td>60</td>
<td>240</td>
<td>406</td>
</tr>
</tbody>
</table>

7.3 Present land use systems scenario

In this and the following sections, features and results of each scenario will be discussed in relation to the base scenario. In order to save space, Table 7.8 is presented with the value of the objective function of the base scenario and the present land use systems scenario, and of the sustainability policy related scenarios: biocide reduction (three variants), price of biocide and soil nutrient depletion.

In the present land use systems scenario, farms can only select LUSTs defined on the basis of the farm survey data, i.e. the actual technologies
currently in use, not the potential ones. The value of the objective function is 24% lower than in the base scenario (Table 7.8). However, per farm type the picture varies greatly. The fertile, well-drained soils (SFW) are used for low income yielding tree plantations, while nearly all unfertile, well-drained soils (SUW) are planted with palm heart. The present technology needs much labour, resulting in a lot of off-farm work on other farms within the Neguev. Therefore, no labour can be spared to work on plantations outside the Neguev, reflecting the collective viewpoint of the model: the objective function is the sum of the farm type incomes. From an individual farm type point of view, some would be better off by working on a plantation. For example, in the present land use systems solution farm type 1 would work more than half of the available work days on other farms in the Neguev at a wage less than half of that on a plantation. Nevertheless, by working for other farmers, these are able to produce more palm heart, resulting in the highest (collective) objective function value. The problem of a collective objective function in a model aiming to approximate farm level choices regarding land use in a (sub-)regional setting, is discussed in more detail in Appendix 5.

Nutrient depletion in the present land use scenario differs from the base scenario: 7.6 kg ha\(^{-1}\) N is added to the soil per year, while 0.2 kg ha\(^{-1}\) P and 10.7 kg ha\(^{-1}\) K are depleted per year. The N added is due to the ammonium nitrate applications for palm heart. The biocide index is 144 ha\(^{-1}\) year\(^{-1}\), an increase of 380% compared to the base scenario, due to the high herbicide use in the present method of palm heart cultivation in the Neguev.

Even though only present LUSTs were used, the optimal land use in the present land use systems scenario differs from the actual 1991 land use in the Neguev (Table 6.1, Section 6.2). Most obvious are the discrepancies in the areas with pasture (of which none appears in the present land use systems scenario) and with annual and perennial crops (nearly 2,200 ha palm hearts in the present land use systems scenario, and no other crops). Several reasons might be forwarded for the difference between land use in reality and in the present land use systems scenario.

First, linear programming is not the most suitable methodology to explain present land use. Three main arguments apply. a) Although the objective of maximising net benefits might be plausible as a first approximation of the actual farmer objectives, farm households typically have complex objectives of which income maximisation might be one. Other possible objectives are food security, regularity of cash income,
risk minimisation and social objectives. b) With regard to the activities, the model takes only eight land use types into account, while in reality more options exist. Also, the input-output coefficients used in the model can only be an estimation of the diversified coefficients in reality. c) Constraints regarding available resources are limited to land and labour in the model, while in reality farms face other constraints as well, for example credit. As the number of binding constraints determines the number of positive variables in the optimal solution of a linear programming model, the optimal solution specialises in a limited number of activities only. The number of activities thus selected are less than would have been selected if all constraints relevant to the actual situation had been included in the model.

Secondly, part of the difference might also be explained by the aggregate nature of the model. In reality each farm takes its own decisions, independently of the other farms, while the model takes into account common (sub-regional) objective and constraints.

Finally, linear programming indicates an optimal solution in the long-term. In reality, short-term considerations, like actual land use, credit availability and maturation periods of, for example, perennial crops, are also important.

7.4 Biocide reduction scenario

The rationale behind the biocide reduction scenario is to examine the consequences for land use, incomes, employment, and nutrient depletion of a policy aimed at a considerable reduction of biocide use. As an example, a 50% reduction in the index value of biocides applied in the Neguev in relation to the base scenario is considered. Three variants are analysed: a) an overall reduction at the sub-regional level without specifying reductions per farm type; b) the same overall reduction, but with the additional specification that each farm type must reduce its biocide use by 50% in comparison with the base scenario; and c) the same overall reduction, but the reduction distributed over the farm types in proportion to the area of each farm type.

Variants b) and c) might appear more attractive from a policy implementation point of view, as they are better targeted at the individual land users, and thus likely to be more equitable. On the other hand, the implementation costs of variants b) and c) for the government will be higher than of variant a). Furthermore, the implementation of variant a) might be delegated to an (up to now non-existent) association of farmers.
Comparing the three biocide reduction scenario variants, the reduction of biocide use differs per farm type (Table 7.9). In variant a), an almost complete reduction of biocide use is obtained through a reduced biocide use in farm type 5, while in variants b) and c) the reduction is assumed to be more evenly spread among the farm types.

Table 7.9 Biocide use index per farm type for base and biocide reduction scenarios (index value ha\(^{-1}\) year\(^{-1}\))

<table>
<thead>
<tr>
<th>Farm type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Neguev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>13.8</td>
<td>30.8</td>
<td>29.4</td>
<td>35.8</td>
<td>32.3</td>
<td>30.0</td>
</tr>
<tr>
<td>Biocide a (50% reduction Neguev level)</td>
<td>13.8</td>
<td>30.8</td>
<td>29.1</td>
<td>35.8</td>
<td>6.7</td>
<td>15.0</td>
</tr>
<tr>
<td>Biocide b (50% reduction per farm type)</td>
<td>6.9</td>
<td>15.0</td>
<td>14.7</td>
<td>17.9</td>
<td>16.2</td>
<td>15.0</td>
</tr>
<tr>
<td>Biocide c (50% reduction per ha)</td>
<td>13.8</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>14.8</td>
</tr>
</tbody>
</table>

The effects on income are small (Table 7.8), less than 1%. Slightly more labour is employed within the Neguev and less on plantations. The land use pattern is similar to that in the base scenario. However, in palm heart, the technology using herbicides is partly replaced by a technology using manual weeding, while maintaining other inputs and outputs at the same level. The replacement is stronger in variant c) than in variant b) which is in turn stronger than in variant a). Finally, nutrient depletion in the biocide reduction scenarios (all variants) is exactly the same as in the base scenario. This is due to the fact that fertilizer inputs and yields are the same in both technologies.

For variant c) Schipper et al. (1995b: 389-390) present the results of a further tightening of restrictions on the use of biocides, reproduced in Table 7.10. "Whereas the total area under palm heart remains constant, technology choice is pushed towards production techniques which use manual weeding instead of herbicides. As a result, hardly any reduction in farm household income occurs. Labour productivity, defined as the gross margin per labour day worked, decreases with increasing manual weeding. On the other hand, land productivity, defined as the difference
of the value of production and the input costs per ha per year, slightly increases because of reduced herbicides costs. The shadow price of the biocide index increases with further tightening of biocide use." It can be added that Table 7.10 shows the trade-off between economic surplus and a biocide restriction.

It is interesting to make a brief detour into the field of multiple goal linear programming (MGLP). In the present study, economic surplus as a goal is formulated in the objective function (as ‘goal variable’ in the terminology of MGLP, Section 5.2.1), while the biocide restriction as a goal is formulated in a constraint to the linear programming model (as ‘restricted variable’ in the terminology of MGLP, Section 5.2.1, in this case of the ‘less than’ or ‘equal to’ type). In MGLP, the biocide restriction would also have been formulated as a goal to be minimised in the objective function in a separate run of the model. In that run, the economic surplus should have been formulated as a goal in a constraint (of the ‘more than’ or ‘equal to’ type) as a minimum biocide use also occurs at a zero economic surplus. Increasing the minimum economic surplus constraint stepwise, the same trade-off between economic surplus and biocide use is obtained as in Table 7.10\textsuperscript{129}. Thus, analysing the trade-off between economic surplus and biocide use as presented in Table 7.10, makes a separate run with a minimum biocide use objective function and a minimum economic surplus constraint superfluous.

Section 7.2 concluded that the aggregation bias is not important for studying land use in the Neguev settlement. In the base scenario, the overall economic surplus with only one farm type is just 0.06\% larger than with five farm types. Nor did the land use change much if only one farm type is identified instead of five. The question can be raised whether the aggregation bias remains that small if more farm type specific constraints are introduced, which can not be exchanged among farm types.

\textsuperscript{129} See Romero & Rehman (1989: 137-147) for a comparison of the trade-off between income and the variance of income obtained in so-called MOTAD (Minimisation Of Total Absolute Deviation) risk programming models with the same trade-off obtained in multiple goal and compromise programming models, having the same goals of maximum income and minimum income variance.
Table 7.10  Influence of biocide use restrictions, as a percentage of the use in the base scenario, on economic surplus, land and labour productivity, and areas with palm heart, both with and without herbicides

<table>
<thead>
<tr>
<th>Scenario</th>
<th>base¹</th>
<th>50%²</th>
<th>40%</th>
<th>30%</th>
<th>20%</th>
<th>10%</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>economic surplus per farm (Colones 10⁶ year⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>417.6</td>
<td>413.7</td>
<td>413.0</td>
<td>412.2</td>
<td>411.5</td>
<td>410.7</td>
<td>410.2</td>
<td>409.8</td>
</tr>
<tr>
<td>shadow price of total biocide constraint³ (Colones constraint unit⁴)</td>
<td>0</td>
<td>0</td>
<td>59.4</td>
<td>59.4</td>
<td>59.4</td>
<td>60.1</td>
<td>62.3</td>
<td>78.9</td>
</tr>
<tr>
<td>biocide use (index value ha⁻¹ year⁻¹)</td>
<td>30.0</td>
<td>14.8</td>
<td>12.0</td>
<td>9.0</td>
<td>6.0</td>
<td>3.0</td>
<td>1.5</td>
<td>0.3</td>
</tr>
<tr>
<td>land productivity⁵ (Colones 10³ ha⁻¹ year⁻¹)</td>
<td>92.4</td>
<td>93.0</td>
<td>93.2</td>
<td>93.3</td>
<td>93.4</td>
<td>93.5</td>
<td>93.6</td>
<td>93.6</td>
</tr>
<tr>
<td>labour productivity⁶ (Colones day⁻¹)</td>
<td>620</td>
<td>599</td>
<td>595</td>
<td>591</td>
<td>587</td>
<td>583</td>
<td>581</td>
<td>579</td>
</tr>
<tr>
<td>palm heart with herbicides (ha)</td>
<td>2676</td>
<td>1177</td>
<td>893</td>
<td>596</td>
<td>299</td>
<td>29</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>palm heart without herbicides (ha)</td>
<td>0</td>
<td>1499</td>
<td>1783</td>
<td>2080</td>
<td>2377</td>
<td>2647</td>
<td>2673</td>
<td>2676</td>
</tr>
</tbody>
</table>

¹ Base scenario without any restriction on the use of biocides.
² Biocide use restricted at 50% of the use in the base scenario; similar for the remaining columns.
³ A shadow price of a constraint indicates the decrease in the objective function as a result of tightening the constraint by one unit. In this case the shadow price refers to the total biocide constraint rather than to the constraints per farm type.
⁴ The overall biocide constraint is not binding, and neither is the constraint for farm type 1; however, the constraints for farm types 2 to 5 are binding. The constraints per farm type have a weighted average shadow price of Colones 52.6. The weights are the respective right hand side values of the constraints.
⁵ Land productivity is defined as the difference between the value of production and the input costs per ha per year.
⁶ Labour productivity is defined as the gross margin per labour day worked.
The farm type specific biocide constraints in variants b) and c) of the biocide reduction scenario are suitable examples. Comparing the economic surplus of the model with five farm types with the surplus of the model with only one farm type for variants b) and c), gives aggregation biases of 0.07% and 0.08%, respectively. More farm type specific constraints do therefore increase the aggregation bias, but the aggregation bias remains of limited importance in the present model.

7.5 Price of biocide reduction scenario

In the price of biocide scenario, the prices of all biocides are doubled, for example, via an extra sales tax. The effect of doubling the price increase of biocides is a 1.3% reduction in the objective function (Table 7.8), 0.4% more than in the biocide reduction scenarios, while the use of biocides is hardly reduced at all. Land use is the same as in the base scenario. The reason for this low reduction of biocide use is the small fraction that the costs of biocides form in the total input costs. In addition, even at a doubling of the biocide price, substitution of herbicides by hand weeding is still relatively expensive.

130 In variant a) the biocide constraint is not farm type specific, but operates at the Neguev level. The aggregation bias with a biocide constraint at the Neguev level is 0.06%, the same as without such a constraint.

131 This result contrasts with findings based on a farm household model for a 20 ha farm with 1.8 labour year available in the Atlantic Zone of Costa Rica. The response to a 1% increase of the biocide price is a 2% reduction in biocide use, a considerable change in the cropping pattern, consisting of maize, beans and cassava, and resulting in a 0.3% income reduction (Kruseman et al., 1995). Using a different version of the same model, Kuyvenhoven et al. (1995) report for a 10% increase in the biocide price a 1% reduction in biocide use, hardly any change in the cropping pattern, consisting of palm heart, cassava and beans, and resulting in a 3% income reduction. Although the income reduction is proportional in both versions, biocide reduction and the change in cropping pattern is not. This can be explained by the introduction of palm heart in the latter version of this model. Palm heart is so attractive, that a change of the biocide price is not followed by a change in the area of crops, resulting in a slight reduction of biocide use only. This more muted response corresponds better to the very low response to a reduction of the price of biocide in the REALM model of the Neguev settlement.

The remaining difference in responses between the farm household model and REALM must be ascribed to differences in options, constraints and coefficients, and the objective functions, apart from the difference in the level of analysis.
7.6 Soil nutrient depletion scenario

In the soil nutrient depletion scenario, the acceptable depletion of N, P and K is restricted for each land unit within each farm type. Each farm type has to use each land unit in such a way that the depletion per year for N, P and K does not exceed so-called 'critical nutrient losses' in a ten year period. Up to the point of critical losses it is assumed that the performance of the land use types, especially the yield, is not influenced. For each nutrient in each land unit a separate assessment of this critical loss is made on the basis of nutrient and soil specific factors (Table 7.11) (Jansen et al., 1995).

The restriction on the depletion of soil nutrients results in a 2.8% reduction of the objective function in comparison to the base scenario (Table 7.8). Similar reductions of this function occur for each farm type. Employment also hardly changes. Part of the area with the palm heart zero fertilizer technology is replaced by palm heart with a technology that uses half the amount of fertilizer (with N, P and K) needed to reach the highest possible yield (Jansen & Schipper, 1995). In this way, the depletion caused by the zero fertilizer technology is compensated, while the farm types are able to maintain the area with palm heart as a whole. Also, more tree plantations are created than in the base scenario.

As an alternative to a restriction on nutrient losses, the losses could be valued in the objective function, taking into account fertiliser efficiencies. In this way, the nutrients are valued at their replacement costs (Ehui & Spencer, 1993). In doing so, the valued nutrient losses act like a penalty to be deduced from the economic surplus. The resulting objective function could be compared to the real net national income concept (Dasgupta & Mäler (1995: 2404-2405), in which an accounting value of the depreciation of fixed capital (manufactured and natural capital) is deducted from the gross national income. Several attempts have been made to green the national accounts. For Costa Rica as a whole, on the basis of estimated soil erosion, not taking into account fertiliser efficiencies, Solórzano et al. (1991: 5) estimate the soil depreciation costs, in terms of nutrient losses, in 1984 to be about 9% of the value added in agriculture.

In the present model land use would not be different (including the 2,676 ha with zero-fertiliser palm heart!) from that in the base scenario, if the nutrient losses are valued at their 1991 market price. The objective function value decreases by 3.3% (Schipper et al., 1995b). Even valuing the nutrient losses at three times the market prices does not alter land use. However, valuing the nutrient losses at four times the 1991 prices leads to a different optimal land use. In that case, the fertile well-drained soils (SFW) are used for tree plantations (instead of palm heart), while the unfertile well-drained soils (SUW) have a combination of zero-fertiliser palm heart and palm heart with a maximum fertiliser application. The results correspond with similar effects reported in Stoorvogel (1995b: 106).
scenario. The changed land use results in a 4% reduction of the biocide use index.

Table 7.11  Total amount of nutrients (kg ha\(^{-1}\)) and permissible yearly losses (kg ha\(^{-1}\) year\(^{-1}\)) in the top 20 cm of the three soil types in the Atlantic Zone

<table>
<thead>
<tr>
<th>Soil type</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>total</td>
<td>loss</td>
<td>total</td>
</tr>
<tr>
<td>SFP(^1)</td>
<td>3696</td>
<td>37</td>
<td>539</td>
</tr>
<tr>
<td>SFW(^2)</td>
<td>4831</td>
<td>48</td>
<td>299</td>
</tr>
<tr>
<td>SUW(^3)</td>
<td>3610</td>
<td>36</td>
<td>278</td>
</tr>
</tbody>
</table>

\(^1\) SFP: Fertile poorly-drained soil.
\(^2\) SFW: Fertile well-drained soil.
\(^3\) SUW: Unfertile well-drained soil.

Source: Jansen & Schipper (1995)

The most critical nutrient is K. The critical nutrient loss per ha per year limit is reached on the land units with well drained soils, both fertile (SFW) and unfertile (SUW) in all farm types.

7.7 Price of palm heart scenario

In the price of palm heart scenario the influence of the price of palm heart on the area cultivated with palm heart, and thus on the objective function, is evaluated (Table 7.12). As mentioned in Section 7.2, a decrease of the palm heart price could result from a production increase in the Neguev (or elsewhere in Costa Rica). Therefore, only the consequences of a possible price reduction are evaluated here.

As palm heart is selected in the base scenario’s optimal solution, it is obvious that a price decrease of palm heart will reduce the objective function’s value. However, there is only a drastic reduction in area under palm heart when the price is 20% lower than the base scenario price. Still, even at a 50% reduction of its price, the total area with palm heart (1004 ha) remains much larger than the actual area in the Neguev (138
ha, Table 6.1, Section 6.2). This is an indication that palm heart is a very attractive land use compared to the alternatives in the model. It is interesting to note that the palm heart area is first reduced on more fertile lands, although the yields are higher than on unfertile lands. The rationale behind this finding is that fertile lands have relatively better alternatives for palm heart than unfertile lands. In other words, the unfertile lands have a *comparative* advantage with respect to palm heart.

Table 7.12 Effects of a decreasing palm heart price\(^1\) on objective function\(^1\) and areas with palm heart\(^1\)

<table>
<thead>
<tr>
<th>Variant of <em>price of palm heart</em> scenario</th>
<th>price palm heart</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95</td>
</tr>
<tr>
<td>objective function</td>
<td></td>
</tr>
<tr>
<td></td>
<td>98</td>
</tr>
<tr>
<td>palm heart on SFW(^2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>palm heart on SUW(^3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>total palm heart</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

\(^1\) As a percentage of the value in the *base* scenario.
\(^2\) SFW: Fertile well-drained soil.
\(^3\) SUW: Unfertile well-drained soil.

The differences in land use between scenarios can be displayed on maps prepared by the geographic information system of MODUS (Stoorvogel, 1995a). As an example, the land use in the *base* scenario is compared with that in the 50% price reduction variant of the *price of palm heart* scenario in Figure 7.1. It clearly shows the reduction of the palm heart area together with the resulting increases of areas with cassava, maize, pasture with cattle, and tree plantation.
Maps of land use in the Neguev: base and 50% reduction variant price of palm heart scenario

(for a color copy see outside back page)
7.8 Price of labour scenario

Labour forms a significant part of production costs and therefore the value of the objective function can be expected to be sensitive to its price. However, since land use systems use labour in different proportions, the influence of a change in the price of labour depends on the relative use of labour in relation to the net benefits of an activity. Furthermore, labour is both a cost (household on-farm labour and hired labour) and a benefit (off-farm work on other farms within the Neguev and on plantations). This implies that a priori the effect of wage changes on the model is restricted. A low sensitivity to wage changes is well known from macro-economic models, but also occurs in linear programming models of the agricultural sector, both of countries as a whole as well as of (sub-)regions within countries. Examples of this phenomenon can be found in Kutcher & Scandizzo (1981: 179-183), Duloy & Norton (1973b), Duloy et al. (1973) and Howell (1983).

In REALM, the total of hired labour is equal to off-farm work on other farms (no labour can be hired from outside the Neguev). Since the hired labour wage is 10% higher than the wage for off-farm work on other farms due to transaction costs, the exchange of labour within the Neguev implies a net cost to the model. As the (reservation) wage in the base scenario for household on-farm labour is lower than the wage for plantation work, a uniform percentage decrease in all wages increases the attractiveness of on-farm activities relative to working on a plantation, while an equal percentage increase of all wages has the opposite effect.

Analysing changes in the price of labour, it can be observed that a price change leads to a less than proportional change in the value of the objective function (Table 7.13). In other words, lower wages lower the economic surplus, even though the response is low, while higher wages do the opposite.

The effects on land use are even more muted. Decreasing the price of labour by 5% leads to more on-farm activities - a somewhat (0.1%) larger area of palm heart - and less off-farm work on plantations (-3.7%). Because the palm heart area increases slightly, soil nutrient depletion is also slightly higher, as is the use of biocides. However, further decreases in the price of labour (at least as much as -25%) have no effect at all on land use. In contrast to wage decreases, wage increases (at least up to 25%) do not have any effect on land use or on plantation work.
Table 7.13 Changes in the value of the objective function: base scenario compared to price of labour scenario

<table>
<thead>
<tr>
<th>% change in wages</th>
<th>-25</th>
<th>-20</th>
<th>-15</th>
<th>-10</th>
<th>-5</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>% change in objective function value</td>
<td>-1.4</td>
<td>-1.1</td>
<td>-0.8</td>
<td>-0.6</td>
<td>-0.6</td>
<td>0</td>
<td>0.3</td>
<td>0.6</td>
<td>0.9</td>
<td>1.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

As outlined above, the model REALM is rather insensitive to changes in wages, because labour is both a cost and a benefit. Furthermore, no labour can be attracted from outside the Neguev. However, the (binding) labour constraints have an important impact on land use decisions, for example the large area with palm heart. This is confirmed by shadow prices of the monthly labour constraints, which are much higher than the wage rate for several months. Given a certain structure of land units and land use types, the costs and availabilities of other than land factors of production determine the use of land. In this case it concerns labour, but by the same token it could have been capital. The same would apply to other scarce factors or opportunities, such as a limited demand. Including a possibility to hire labour from outside the area in the model might change the resulting land use (Appendix 5).

REALM is an optimisation model regarding land use. Elsewhere (Section 5.1) it has been stated that decisions regarding land use are taken at the farm level, but that these decisions can be influenced by policy measures decided upon at the (sub-)regional level. Therefore, it was deemed important to simulate the situation at the farm level regarding objectives, options and constraints in order to be able to evaluate possible policies. Thus, the interpretation of the objective function and the constraints regarding the behaviour of the farmers are crucial. A problem in this respect is that the objective function, being the sum of the economic surpluses of the individual farm types, is a collective surplus.

Land and labour constraints are set at the farm level, although labour is also constrained at the sub-regional level (equalisation of aggregated hired labour with aggregated off-farm work on other farms within the Neguev, equation (6.13); limited aggregated plantation work, equation
This way of formulating constraints is thought to be a reasonable approximation of reality. The equalisation constraint of inter-farm labour within the sub-region is an equilibrium condition of the model. Such conditions or 'system constraints' are also called 'closures' (Robinson, 1989), in this case at the sub-regional level.

As the objection function is a collective surplus, it might be beneficial for the model to have a higher surplus of one farm type at the cost of that of another. An example of this occurred in the present land use system scenario (Section 7.3). Such a set-up could be interpreted as representing a situation in which a planner at the level of the Neguev dictates land use and allocates labour among the farms. In doing so, the planner tries to maximise the total economic surplus in the Neguev, but might find it necessary to sacrifice economic surplus of one or more farm types in order to increase the surplus of other farm types by a larger amount. Thus, the model does not represent a situation in which each representative farm is maximising its own surplus and in which all farms compete for the existing pool of labour in the Neguev (Norton, 1995b: 10). Norton suggests a number of approaches to get around this difficulty. The model could be modified in such way that the farm types correspond better to the idea of individual decentralised decision makers. Using an iterative procedure, one of these approaches is to introduce the possibility of hiring labour each month from outside the Neguev at increasing wage rates until the wage is so high that no labour from outside will be hired. The resulting labour use per farm type, cropping pattern and income per farm type can be considered as resulting from a competitive labour market. This approach is elaborated in Appendix 5.

Such a formulation is possible and leads to a different distribution of economic surplus over the farm types, more in accordance with a competitive labour market. However, the procedure is cumbersome, and does not take away all features of collective behaviour.

### 7.9 Discount rate scenario

The discount rate is used to calculate the present value of future cost and benefits and to convert them to annuities (Section 6.3). In the base scenario a 10% discount rate was assumed. The discount rate scenario serves to examine the influence of the discount rate on land use and related variables.

Palm heart, a perennial crop, remains the most important land use in all variants of the discount rate scenario. With perennials, benefits tend to be concentrated in later years, while most costs are made in the initial
years. Palm heart, being the most important crop, contributes most to the economic surplus. This explains why the objective function decreases with an increasing discount rate (Table 7.14). The reverse is true for plantation work. This is an annual activity with equal net benefits in all years. At higher discount rates such activities are more attractive than 'investment' activities like perennials.

The change in land use patterns as a result of a change in the discount rate needs more explanation. At low rates, extensive cattle production is attractive, while at higher rates the present value of benefits in later years diminishes quickly (Table 7.14). This applies especially to the valuation of the stock in year 20, the last year in the pasture with cattle LUSTs. Note also that only at discount rates of less than 10% is it worthwhile using fertile poorly-drained soils (SFP).

With regard to the fertile well-drained soils (SFW), teak plantations are attractive at discount rates up to 3%, melina plantations at rates between 5 and 10%, while no tree plantations would be created at rates of 15% and higher (Table 7.14). For comparable wood prices, teak is harvested later than melina, explaining the change from teak to melina at higher discount rates.

The explanation of changes in the areas under palm heart and cassava is problematic. First, the changes are not consistent. With increasing discount rates, the area under palm heart on fertile well-drained soils (SFW) increases first, although slightly, and decreases at rates above 10% (Table 7.14). In conjunction with these changes, more cassava is planted at higher discount rates, reinforced by the disappearance of tree plantations. The main conclusion is that, although the benefits per hectare of palm heart decrease at higher discount rates, it is still the most attractive land use, in view of the alternatives offered to the model. A similar conclusion can be reached for the unfertile well-drained soils (SUW). Up to a discount rate of 10%, the area of palm heart is slightly reduced in favour of cassava, while at higher rates, the palm heart area increases at the expense of cassava (Table 7.14).

As land use changes occur with changing discount rates, it is to be expected that soil nutrient depletion and biocide use also change. However, the overall effects turn out to be small. Because of the larger area in use at discount rates up to 5%, the soil nutrient depletion and the biocide use is somewhat higher than at rates of 10 to 20%.
Table 7.14 Value of objective function, plantation work and land use: *base* scenario compared to *discount rate* scenario

<table>
<thead>
<tr>
<th>discount rate (%)</th>
<th>0</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>objective function value (Colones $10^6$ year$^{-1}$)</td>
<td>453</td>
<td>443</td>
<td>435</td>
<td>418</td>
<td>400</td>
<td>382</td>
</tr>
<tr>
<td>plantation work (days $10^3$ year$^{-1}$)</td>
<td>314</td>
<td>329</td>
<td>329</td>
<td>329</td>
<td>332</td>
<td>332</td>
</tr>
<tr>
<td>pastures with cattle on SFP$^1$ (ha)</td>
<td>372</td>
<td>422</td>
<td>422</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>cassava on SFP$^1$ (ha)</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>palm heart on SFW$^2$ (ha)</td>
<td>725</td>
<td>727</td>
<td>727</td>
<td>732</td>
<td>690</td>
<td>692</td>
</tr>
<tr>
<td>cassava on SFW$^2$ (ha)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>70</td>
<td>69</td>
</tr>
<tr>
<td>teak plantation on SFW$^2$ (ha)</td>
<td>37</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>melina plantation on SFW$^2$ (ha)</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>29</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>palm heart on SUW$^3$ (ha)</td>
<td>1950</td>
<td>1944</td>
<td>1944</td>
<td>1944</td>
<td>2012</td>
<td>2011</td>
</tr>
<tr>
<td>cassava on SUW$^3$ (ha)</td>
<td>248</td>
<td>254</td>
<td>254</td>
<td>254</td>
<td>185</td>
<td>186</td>
</tr>
</tbody>
</table>

$^1$ SFP: Fertile poorly-drained soils.
$^2$ SFW: Fertile well-drained soils.
$^3$ SUW: Unfertile well-drained soils.

### 7.10 Summary of scenarios

An objective of REALM is to evaluate the effects of changing trends in land use determinants and different policies on land use decisions. It is supposed that farm households take such decisions on the basis of their objectives, options and limitations. Therefore, a model to evaluate land use decisions should be a model that represents as closely as possible the situation of the farm households. Having such a model, the effects of changing trends in land use determinants and policies are studied in scenarios. The outcome of a scenario is compared with the solution in a base scenario.

In the model exercises, a comparison was first made between the *base* scenario, in which all LUSTs can be selected by the farm types, and a *present land use systems* scenario, in which farm types can only select LUSTs with technologies defined on the basis of the farm survey in
1991/92. The difference indicates the effects of improved\textsuperscript{133} technology on land use, incomes and environmental indicators. In both scenarios, as is the case in all scenarios, land use is dominated by palm heart. The economic surplus in the present land use systems scenario is 24\% lower than in the base scenario, while nutrient depletion and biocide use is higher. An improved technology thus has positive effects on incomes as well as on the environment. Land use in the present land use systems scenario differs considerably from the actual situation, for example with regard to the area under palm heart. This indicates that, at least as formulated in REALM, linear programming is not a suitable technique for explaining present land use.

Comparing the base scenario with scenarios regarding policies more aimed at a sustainable land use, it can be concluded that the trade-off between a reduction of biocide use or nutrient depletion, and the economic surplus are not unfavourable. Stricter standards for biocide use and nutrient depletion do not necessarily lead to large income reductions in the Neguev settlement in Costa Rica for the range of policy measures studied. An overview of the changes in a number of key variables, as percentages of their values in the base scenario, caused by a change in a policy measure or land use determinant, is presented in Table 7.15.

The trends in land use determining factors studied relate to the price of palm heart, wages and the rate of discount. The price of palm heart is important as it is the most attractive land use in the area. Price reductions may occur for two reasons. First, the international price of palm heart might decrease because of extra supplies from competitors outside the Neguev, either inside of outside Costa Rica, or because international demand is not catching up with supply. Secondly, if large areas in the Neguev are planted with palm heart, increased production would considerably boost the supply from Costa Rica to the world market. As Costa Rica is a large supplier of palm heart, such extra supplies could cause decreasing prices, even without extra supplies from elsewhere. Even at a 50\% lower price, the model results indicate that still a large area would be planted with palm heart, considerable larger than is actually the case. This is an indication that palm heart is indeed a very attractive land use compared to the alternatives in the model.

\textsuperscript{133} In the present context, improved technology compared to the technology of present land use systems means higher yields with respect to land and/or labour, and/or less nutrient depletion or biocide use.
Table 7.15   Results of alternative scenarios (in % changes from base scenario)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Economic surplus(^1)</th>
<th>Gross margin</th>
<th>Return to land etc.(^2)</th>
<th>Nutrient balance</th>
<th>Biocide use index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Palm heart price - 50%</td>
<td>-28</td>
<td>-38</td>
<td>-27</td>
<td>-16</td>
<td>-16</td>
</tr>
<tr>
<td>Biocide price + 100%</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biocide use 50% of base use</td>
<td>-1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soil nutrient depletion</td>
<td>-3</td>
<td>-3</td>
<td>-2</td>
<td>-12</td>
<td>57</td>
</tr>
<tr>
<td>Labour costs + 25%</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^1\) The economic surplus equals the value of the objective function.

\(^2\) Return to land, own capital and management of the farm.

In REALM, (binding) labour constraints have an important impact on land use decisions, for example on the large area with palm heart. This is confirmed by the shadow prices of the monthly labour constraints, which are much higher than the wage rate for several months. Given a certain structure of land units and land use types, the costs and availabilities of other than land factors of production determine the use of land. In this case it concerns labour, but by the same token it could have been capital. The same would apply to other scarce factors or demand constraints.

It was shown that REALM is rather insensitive to changes in wages, primarily because labour is both a cost and a benefit in the model. The model pretends to represent the situation of farms with respect to objectives, options and limitations. However, because the sum of the surpluses of the individual farm types is maximised, it behaves like a collective entity. This shows up in the allocation of labour to off-farm work, either working on other farms inside the Neguev or on plantations. At times, this depresses the economic surplus of one farm type by a certain amount in order to increase the surplus of other farm types by an even larger amount. Therefore, an alternative approach to the formulation of the labour market is provided in Appendix 5. In this alternative approach each farm type bids for hired labour, which can come from other farm types within the Neguev or from outside the Neguev. Such a
formulation is possible and leads to a different distribution of the economic surplus over the farm types, more in accordance with a competitive labour market. However, the procedure is cumbersome, and does not take away all features of collective behaviour.

As a number of LUSTs in REALM are perennials while the model is a one-period model, costs and benefits in each LUST are discounted. Given different profiles of costs and benefits over time, the discount rate affects the relative attractiveness of the LUSTs. For this reason the influence of the discount rate on land use was studied. The results are as expected: at lower discount rates, long term LUSTs are more attractive than short term LUSTs, and vice versa at higher rates. However, at all discount rates studied, palm heart remains the most attractive land use.
8 DISCUSSION AND CONCLUSIONS

In the present study an approach to land use analysis is outlined: USTED (Uso Sostenible de Tierras En el Desarrollo). In doing so, the study aims to contribute to a methodology for land use analysis, looking for a form of land use that provides increasing incomes to farm households and farm workers, and at the same time maintains the productive capacity and other environmental services of land resources.

Land use planning and land evaluation

Although the question of the capacity of the earth to adequately feed mankind was an early concern for economists (e.g. Malthus, Ricardo), land use studies as such fall within the domain of agronomy and soil science. Therefore, the study starts with a review of land evaluation and land use planning from an economic angle in Chapter 2, while suggestions for improvement are provided in Chapter 4. The economic critique concerns a) the selection of land use types for evaluation, b) the definition of land use types without sufficiently taking into account farm systems of which they form a part, c) the often rather qualitative way of describing the land use types, and d) the definition of suitability levels which are economic in character by comparing benefits with costs, even for the biophysical part of a land evaluation. The suggestions for improvement are to consider land use types, in combination with land units, as components of farm systems, which leads to the type of land use analysis as outlined in the present study, and to design biophysical suitability definitions for the biophysical part of land evaluation. Then, on the basis of biophysical input and output data, partial budgets per land use system could be prepared. However, economic analysis as such is more relevant and feasible at the farm and (sub-)regional levels of analysis.

Economic theory and land use

Economic theories of land use are reviewed in Chapter 3. Land is defined as an economic resource. After a brief examination of prospects for agricultural production and population growth, and problems of land degradation, the concept of sustainable development is discussed. The study opts for the definition of Pearce & Turner (1990: 24): maximising
the net benefits of economic development, subject to maintaining the services and quality of natural resources over time. In conjunction with the rules for resource use they provide, this definition can be made operational for land use analysis.

After reviewing theories of resource economics, it is concluded that these theories are relevant and provide 'food for thought', but lack direct applicability to more practical cases of land use analysis. Ideas of land economics (e.g. land use as a multidisciplinary study object; views on conservation), concepts from classical economics concerning scarcity and rent, and views on mitigated scarcity of land through the inventiveness of land users induced by the same scarcity (Boserup) are in many instances pertinent, but not always directly applicable. Application of optimal control theories and of theories linking the areas of economy and ecology, although in principle on the right track too, are even more difficult to envisage.

Concepts of cost-benefit analysis and of farm management, production economics and household economics are more directly applicable to land use questions. Cost-benefit analysis supports decisions regarding investment in land or in perennial crops, livestock activities and reforestation. Farm management, production economics and household economics provide insights into questions at the farm level of what, how (including by whom) and when to produce.

Other important or useful concepts originate from regional economics (comparative advantage), or point to institutional problems, in particular questions concerning land tenure and contradictions between different (groups of) land users. Finally, the existence of 'unsolved' problems within economics, like micro-macro linkages, aggregation problems and partial versus general equilibrium analysis, at times highly relevant for land use issues, should caution against undue belief in the extent to which the results are able to mirror reality.

Land use analysis

Apart from making suggestions for improving land evaluation, Chapter 4 also provides an outline for the role of economics within land use analysis. The background of this outline is formed by a skeleton model of the agricultural sector, concepts of regional agricultural planning, in particular a comprehensive resource based approach, and the so-called LEFSA sequence for land use planning. The basic idea is to distinguish levels of analysis and to consider the analyses made by several disciplines (at least: agronomy, soil science and economics) at each of these levels. Furthermore, at each of these levels models can be designed, which are
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connected in a modular fashion and which foster multi- or interdisciplinary collaboration. The USTED methodology is an example of such an approach to land use analysis. However, before considering USTED in more detail, Section 4.5 provides an overview of possible models at the activity (land use type / land unit) level, the farm level and the sub-regional level, as well as the linkages between the models.

At the activity level, crop growth simulation models can be used. However, these are often not (yet) sophisticated enough to provide a satisfactory approach to complicated situations of limited nutrient availability and the incidence of pests and diseases. In the majority of the cases one has to rely on information from farmers and experts to construct input-output budgets. The activity level models are incorporated in farm and sub-regional models by extracting relevant input and output coefficients from these models. In view of the differences between farms, the development of models per farm type is advocated in order to diminish possible aggregation biases. In addition it is advocated that the farm level not be skipped by directly constructing a sub-regional model. For this purpose farms need to be grouped in relevant and appropriate farm types. As farm type models represent the decision problem at that level, they should be representative of farm level objective(s), options and constraints. Subsequently, the farm type models can be incorporated into a sub-regional model.

A sub-regional model should be representative of farm level decision making within the context of sub-regional opportunities and constraints, including those created by policy decisions. This can be approximated in two ways. On the one hand this can be done by building a sub-regional model including the farm type models, with an objective function representing the sum of the objective functions of the farm type models. On the other hand, it can be achieved by designing an iterative procedure in which the farm type models are solved first, after which the results of the optimal solutions of the farm type models are incorporated into a sub-regional model, which is then solved with its own objective function. This procedure will have to be repeated several times until both the farm type models and the sub-regional models show satisfactory results. This approach belongs to the area of multi-level planning. It is not selected in the present study because a priori it is not clear whether the results obtained are usable. Furthermore, experiences elsewhere indicate that it would be very time consuming. The first approach is used here, but this has its own problems, in particular that of the collective behaviour resulting from the combination of an objective function, formulated as the sum of the objective functions of each farm type, with a constraint at the
Chapter 8

Sub-regional level, a common resource. Such collective behaviour is contrary to the original intention of the model, which is to mimic farm level behaviour within a regional context. This problem is discussed at length in relation to labour demand and supply in Section 7.8 and Appendix 5.

Linear programming

In Chapter 5 linear programming as a tool for land use analysis is introduced. A discussion of aggregation issues is followed by an extensive discussion of linear programming as a tool for land use analysis. The chapter ends with a description of the necessary and desirable elements of such linear programming models.

Aggregation

The aggregation issues consist of the aggregation bias, the problem that variables exogenous at the farm level become endogenous at the regional level, and the difficulty of analysing decision making at more than one level. The last issue is circumvented by analysing farm level decisions in the light of policy decisions without taking possible feedback into consideration. The second issue occurs, for example, when input and output prices can no longer be considered independent from their supply or demand. This issue is simplified by assuming that for a sub-region, being a geographical part of a region and in its turn a geographical part of a country, the supply or demand is small in comparison to the (inter)national market for the product in question. The first issue, a possible aggregation bias, is of real concern when modelling land use at the (sub-)regional level.

The possible aggregation bias that is of interest here, is the bias introduced by not including farm types in a sub-regional model, not the (unavoidable) bias created by grouping individual farms into farm types. This latter bias is reduced by grouping farms that are alike, possibly through cluster analysis. The aggregation bias of concern here exists because, at the (sub-)regional level, options can be different and resources are available in different proportions than for each individual farm type. For linear models Day (1963) formulated three conditions for aggregating without bias. The farm type models should have proportional objective function coefficients, the same input and output coefficients, and proportional availability of resources. In practice this will never be the case, the situation can only be approximated. In the model of the case study area, the farm types deliberately have the same objective function coefficients, and also the same input and output coefficients. Only the
Discussion and conclusions

The proportional availability of resources is different (also deliberately, through the clustering on the basis of the availability of farm land and labour resources). However, as labour can be exchanged (involving a transaction cost) between farm types, the availability of these resources can become closer to proportional. It turns out that the aggregation bias in the optimal solution is very small, less than one percent of the value of the objective function. This is assessed using an aggregate model in which the farm types are collapsed into one sub-regional super farm. In conjunction with this, land use according to such an aggregate model, at the sub-regional level, is also nearly the same as the use according to the original model with five farm types. Thus, under the conditions in the case study, distinguishing farm types is not important regarding overall land use. Regardless, the different farm types still provide insight into the distribution of a number of outcomes over the farm types, like income and employment. Furthermore, where farm types have different objective function coefficients (e.g. different prices) or have different land use options (e.g. economies of scale in cattle production systems) the aggregation bias will be more important. The same holds if the exchange of a resource between farm types is more limited, or demands higher transaction costs.

A tool for land use analysis

Linear programming models as a tool for land use analysis are discussed with regard to four topics. In the first place, they are compared to similar models for (regional) agricultural sectors, developed in the early 1970s. Models for the agricultural sector in Mexico are just one example (e.g. Duloy & Norton, 1973a). These were inspired by models for the US agricultural sector (e.g. Heady & Egbert, 1964). A comparison between a number of linear programming type of land use models, including the model in the present study, and the Mexican type of sector models shows many similarities with regard to the use of linear programming as such. However, a major advance of the present model is its use within a methodology or system for land use analysis, including modules for detailed description of land use systems, soil nutrient depletion and a geographical information system. Following Erenstein & Schipper (1993), a new element is the use of annuities of present ‘quantities’ over the life span of the land use systems to calculate the input and output coefficients for use in the linear programming model. In this way it is possible to compare land use systems with different life-cycles in a better way.
Sustainability

In the second place, the definition of Pearce & Turner (1990: 24) of sustainable development, in combination with their 'rules' for resource use, is applied to the issue of sustainable land use, in particular where a programming model is employed. Maximising the net benefits of economic development is interpreted as having an objective function that maximises the economic surplus, while subject to maintaining the services and quality of natural resources over time is elaborated through the definition of relevant sustainability indicators which can be incorporated as constraints. In that way the first rule for resource use can be applied: a1) utilise renewable resources at rates less than or equal to the natural rate at which they regenerate, and a2) keep waste flows to the environment at or below the assimilative capacity of the environment (Pearce & Turner, 1990: 24 & 44). The left hand side of a constraint represents the use of a resource or the amount of pollutant to the environment, while the right hand side indicates the ‘natural rate of regeneration’ of a resource or the ‘assimilative capacity’ of the environment. The second rule for resource use is implied in a (linear) programming set-up. This rule is as follows: b) optimise the efficiency with which non-renewable resources are used, subject to substitutability between resources and technical progress (Pearce & Turner, 1990: 24).

The optimal solution of a programming problem is by definition the most efficient use of the resources, given the objective and the options for resource use. The effects of substitution can be studied via shadow prices and sensitivity analysis. Technical progress is incorporated into the model as each land use system is specified for different technologies, including future ones as far as they are known.

Single versus multiple goals

In the third place, single versus multiple goal programming is briefly discussed. In the present study a single goal model is presented. The goal, maximising economic surplus, is supposed to approximate farm level objectives, and thus the behaviour of farmers. This is based on many investigations indicating that farm households show ‘a strong element of economic calculation’ (Ellis, 1993: 76). Therefore, it is plausible to use the hypothesis that farm households have ‘some notion of conditional (or constraint) profit maximisation’. Such a notion of profit maximisation is made operational as the maximisation of an economic surplus. Of course, other objectives like food security, risk minimisation, leisure and the upkeep of farm resources on behalf of future generations also play a role, but are not incorporated in the present model. In
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contrast, multiple goal models often contain objectives that are relevant to policy makers or scientists, for example the minimisation of biocide use, but not to those who ultimately make decisions about land use, the farm households. Therefore, the present model with a plausible objective regarding farm household behaviour is more suitable for exploring the effects of certain policies on land use than multiple goal models.

Econometric analysis

In the fourth place, the issue is raised of using (linear) programming models versus econometric analysis of, for example, production functions as the main methodological focus of the economic contribution to a methodology for land use analysis. It is concluded that programming models are suitable for interdisciplinary collaboration with agronomists and soil scientists, because of the way activities are described through fixed input and output coefficients. As this can be done in varying degrees of detail, technical knowledge can be incorporated, including future potential options. The constituent parts of programming models, objectives, options and constraints, fit into the idea of searching for a 'best' land use, while a proper definition of sustainability can be accommodated. Estimation of production functions is difficult to envisage within a single farm system, while estimation of production functions by using data from different farm systems encounters theoretical objections (Ellis, 1993: 67-76). Furthermore, econometric results are always based on situations from the past. They are not necessarily indicative for the future, particularly in the case of changing circumstances, for example an improved technology. At higher aggregation levels than the farm and sub-region, linear programming might be less suitable for land use analysis, as a number of assumptions (e.g. fixed prices) are less tenable, or would require complex adaptations. Econometric analysis might then be more suitable, also because at these higher levels the data available are more suited to this kind of analysis. In practice, economists should look for instruments suitable for the level and problem of analysis and not shy away from either a programming approach or an econometric analysis.

REALM for the Neguev

In Chapter 6 the case study area, the Neguev settlement in the Atlantic Zone of Costa Rica, is described, in particular with regard to land use. The specifics of the Neguev area plus the methodological considerations outlined in Chapter 5 inspired the construction of the Regional Economic Agriculture Land-use Model (REALM) as a case study. The sub-regional land use model REALM has its strengths and limitations. The model
forms part of a comprehensive methodology for land use analysis (USTED), incorporating a module to store quantitative LUST (Land Use System & Technology) data and linked to a geographical information system. The model is extensive with regard to the technology options for the land use systems considered. Moreover, the location of each different land use can be indicated.

**Technical details / interdisciplinarity**

Since the model is a linear programming model, it is possible to include many land use systems, each with a number of technological options. Because it is a model for the sub-regional level (incorporating different farm types), it permits a more detailed formulation than models for higher (e.g. regional, national) levels of analysis. Each LUST has fixed technical coefficients, estimated on the basis of farm surveys, expert knowledge and simulation models. Such a quantitative approach is conducive to interdisciplinary research, in this case between agricultural economists, agronomists and soil scientists.

**Policy analysis**

From a policy making perspective, the sub-regional level of analysis of the model is a drawback, despite its suitability for interdisciplinary cooperation. For policy making purposes, a model for the entire (Northern part of the) Atlantic Zone of Costa Rica should be made. This would make the model not only much larger and thus more difficult to manage, but also more complex. For example, for a number of products, such as plantain, the supply from this region would form a considerable part of the national supply. In that case, product prices would become endogenous variables in the model which would require reliable data on own and cross price-demand elasticities. Furthermore, the question arises as to what happens in the other regions of Costa Rica. Would an increase in the production of a crop in the Atlantic Zone be matched by a similar increase in the other regions? In other words, one would need some insight into regional cost differences. Extending a sub-regional model to a regional one would not only enlarge and complicate the model, but would require its reformulation as well.

**Labour and land use**

In REALM, (binding) labour constraints have an important impact on land use decisions, for example on the large area of palm heart. This is confirmed by the shadow prices of the monthly labour constraints, which are much higher than the wage rate over several months. Given a certain structure of land units and land use types, the costs and availabilities of
factors of production other than land determine the use of land. In this case it concerns labour, but by the same token it could have been capital.

Because the model contains sub-matrices for each farm type within the sub-region, it approximates farm level resource availabilities, instead of aggregated resources. At the same time, the farm types are not optimised in isolation, since each type has to take into account the sub-regional labour supply and demand. The equalisation of the hired-work availability on all farm types ('demand') with the off-farm labour of all farm types ('supply') within the sub-region is an equilibrium condition of the model. Such conditions or 'system constraints' are also called 'closures' (Robinson, 1989), in this case at the sub-regional level. In the price of labour scenario it can be observed that this type of closure makes the model rather insensitive to changes in wages. Of course, this is also caused by the related feature that labour is both a cost and a benefit in the model. An alternative formulation of the labour market is provided in Appendix 5.

Reality is more
The model leaves out a number of important aspects of reality. First, the model should include more land use types if it is to represent the full range of possibilities available. Examples include banana, roots and tubers (other than cassava), papaya, pumpkin, passion fruit and ornamentals, although not all these land use types are relevant for all farm types. Also, different pasture types should be specified, which leads to another limitation: the way animal production systems are incorporated. At present cattle are linked to pasture at fixed stocking rates. Supplementary feeding from other land use types is not allowed for, which might be realistic for the majority of local pastures where cattle are reared extensively. However, for more intensive management systems with improved pastures, legumes, supplementary feeding etc, fixed stocking rates would no longer be a realistic assumption. The solution can be found by defining 'Animal Production Systems with certain Technology levels' (APSTs), which use products (pasture, cobs, bananas, leguminous leaves) from LUSTs as inputs. These inputs provide the necessary calories, proteins and dry matter to the APSTs. Products of APSTs (e.g. dung) could be used by LUSTs as inputs. In more recent models, follow-ups of REALM, still in the incubator of the Atlantic Zone Programme, APSTs and related features are incorporated.

Extreme solutions
In the solutions of the linear programming model some variables show 'extreme' values, for example the area with palm heart in the base
scenario. Extreme solutions are typical for linear models. If one option is better than another, the linear programming algorithm will include the corresponding activities to their maximum. Furthermore, in an optimal solution of a linear programming model, the number of activities entering the solution can never exceed the number of binding constraints. The extreme solution property can be mitigated by placing bounds on specific variables (most often arbitrary), incorporating crop rotation demands, introducing risk aspects, or incorporating diminishing returns to scale and/or downward-sloping demand curves into the model. An alternative approach is to examine 'near-optimal' solutions as well, for example, those which have an objective function value of not less than a certain percentage of the value in the optimal solution (Jeffrey et al., 1992).

Scenarios

In Chapter 7 scenarios regarding possible land use are analysed. The scenarios relate to policy measures regarding sustainability indicators or regarding developments of land use determining factors. Scenarios include biocide reduction, biocide price, soil nutrient depletion, price of palm heart, price of labour and discount rate scenarios. The results of these scenarios are compared with the results of a base scenario in order to study the effects of environmental policies or of changing land use determining factors. In all scenarios the economic surplus is the objective function.

Reconnaissance

Studying the scenarios can be seen as a reconnaissance of possible developments, given the assumption of one objective that determines land use decisions at the farm level. This contrasts with reconnaissances in multiple goal linear programming (MGLP) models for land use analysis in which the solution space is formed by different objectives. By subsequently solving such a model for different objectives, one can obtain a Pareto optimal solution space in which one objective can only increase at the expense of another objective. The possible solution space of a MGLP model for the Neguev area would be different from the one obtained with the present REALM model of the Neguev. From the point of view of trying to investigate solutions steered by an economically plausible objective, the present model is to be preferred because it is more relevant for studying the effects of changing circumstances or policies on land use and related variables.


**Base case**

The *base* scenario showed possible attractive future land uses. Given yields, input use, and the relative input and output prices, palm heart appears to be an attractive activity. Even when its price is reduced by half, the acreage for this crop would still increase. This result supports the present trend of extending palm heart cultivation in the Neguev. Needless to say the realisation of such a scenario outcome would require a thorough analysis of the marketing prospects of palm heart.

**Assessing sustainability**

A characteristic of the model is that aspects of sustainability are confined to two sustainability indicators: soil nutrient depletion and biocide use. These were considered the most relevant in view of the circumstances of the area. Estimating soil nutrient depletion as a flow variable for each LUST is demanding; moreover, comparing depletion with estimates of the stock of nutrients in the soil, while assuming a period in which the depletion does not affect the land use type in question, thus indicating the limits for resource use, is quite difficult. Indicating limits for resource use, if possible connected to the notion of the ‘natural rate of regeneration’ would be an important area for future - interdisciplinary - research. In addition, the opposite effect of a less fertile soil, due to depletion, on the performance of a land use type is not part of the model. That could be accomplished by incorporating long-term LUSTs, taking into account the effects of a depleted soil, or by making the model dynamic. These technicalities notwithstanding, the soil nutrient depletion scenario shows that a possible restriction on this depletion, at the level of land units within farm types, has a limited effect on farm incomes.

Although arbitrary, it is not too complicated to construct a biocide use index. However, firm statements about the impact of biocides on the environment and about the real assimilative capacity of the environment are very hard to achieve, at least at present. Again, this would be an important research topic. A promising avenue might be to refine the biocide use index into more components, each representative of effects on a different aspect of the environment. Verhoeven *et al.* (1994), for example, estimate the effects of pesticides used in a particular farm in the Netherlands by distinguishing between effects through leaching into ground water, effects on water organisms and effects on soil organisms. In the biocide reduction scenario of the present study an arbitrary reduction of biocide use of half that of the base scenario is assumed, showing that such a reduction in biocide use is possible with only small
effects on farm incomes. Moreover, doubling the price of biocides did not affect its use.

Notwithstanding the difficulties mentioned with regard to the sustainability indicators used, a more general model should also be able to use other indicators of sustainability, for example soil erosion. Using estimates of soil erosion by each LUST is possible, although the quantity of soil loss is not undisputed. However, incorporating relations of one land unit with another is not possible in a linear programming model, as soil loss from one land unit is partly deposited on other land units. This would also be a challenging research subject.

**Farm typology**
The model incorporates different farm types to take into account different resource availabilities at the farm level. The incorporation of different farm household types, each with a different objective, will be challenging, unless the different objectives can be accounted for in the constraints. Examples of such constraints are minimum on-farm food production goals and target incomes in risk models. Some of the risk models can have farm type specific standard deviations of gross income and risk aversion coefficients in the objective function. Another possibility might be two-level (or multi-level) models which are solved iteratively. However, this procedure is complicated, time consuming and very few successful practical applications exist in the literature.

**Finally**

A major conclusion from the comparison of the different scenarios is that, given a certain structure of land units and land use types, land use is determined by the costs and availabilities of other production factors than land. In the Neguev case it is labour, but in other cases it could also have been capital. The same would apply to other scarce factors or demand constraints. In general, research into the functioning of the labour market (or other relevant markets) should therefore have a high priority in future research regarding the sustainability of land use.

In the present study, an economic critique of land evaluation is formulated, in particular with regard to the definition of land use types and the use of suitability definitions that are economic in character, as they relate benefits to costs. As such, it is commendable that non-economists are convinced about the importance of economic considerations. However, in this case these definitions obscure the technical nature of the judgements of agronomists and soil scientists regarding land use types and their suitabilities, which are mainly based
Discussion and conclusions

on yield expectations. Besides, quantitative input and output data of land use systems can never be the sole basis for economic judgements regarding the relative attractiveness of land use systems. Information regarding objectives and constraints at higher levels of analysis, including the farm and (sub-)regional level, is required for this purpose.

Lastly, it is advocated that the expression land use planning be replaced by land use analysis. Land use planning, usually executed at (sub-)regional or higher levels, has a tendency to prescribe the 'best' land use, implying that decisions can be made about land use at these levels. This is almost never the case. Land use decisions are mostly taken at the farm level. Of course these decisions can be influenced by decisions at the (sub-)regional or national level. Proper decision making at these levels requires a thorough analysis of possible land use decisions at the farm level. Such an analysis is a major aim of land use planning. Therefore, land use analysis is preferred over land use planning.
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SUMMARY

Subject

In recent times various concerns have been expressed about present and future land use. Are the land (and water) resources of the earth able to supply sufficient products (food and other) to sustain a growing population and provide increasing incomes to the agricultural population? Will the land and water resources be able to maintain their productive capacity over time, and provide sufficient living space and environmental amenities? Answers to those questions range from being pessimistic (e.g. Brown & Kane, 1995) to optimistic (Penning de Vries et al., 1995). The pessimistic answer is mainly based on extrapolating present trends of population growth and agricultural production and productivity, while the optimistic one is based on comparing population trends with what could potentially be produced by land and water resources in different regions of the world. The concept of land use analysis as developed in the present study could bridge the gap between these two approaches for particular areas.

Since the times of Ricardo and Malthus, problems of feeding the population of different areas and thus of land use have been an explicit concern of economists. Within economics, land economics developed as a special branch, devoted to the study of land resource use from different perspectives. Nowadays, studying land use is part of agricultural economics.

Obviously, land use is also the focus of more technical disciplines like agronomy and soil science. As a result, a separate branch of study developed involving a multidisciplinary assessment of the capability of land for different uses, usually called land evaluation (FAO, 1976 & 1983). Dent & Young (1981: 115) describe land evaluation as "The process of estimating the potential of land for alternative kinds of use." Ideally, such an assessment also incorporates economic and social aspects.

Land evaluation is usually the basis for land use planning (FAO, 1993a). The latter can be loosely described as the allocation of different tracts of land to different uses, aiming at the best land use. ‘Best’ is normally seen from a human point of view, involving objectives, options and constraints.
The present study contributes to the search for a methodology for land use analysis, aiming at a land use which would provide sufficient (and rising) incomes to the agricultural population and at the same time maintains the productive capacity of land. It focuses in particular on the role of economic analysis and addresses the following major research questions.

1) How useful are present approaches within land evaluation and land use planning for analysing land use from an economic point of view? To what extent can they be improved?

2) Economics is rich in different theories; which ones are relevant and how can these theories be used for analysing land use issues?

3) What are the main elements of an economic analysis of land use? What form should collaboration with other relevant disciplines like agronomy and soil science have?

4) What is the role of linear programming within a methodology for land use analysis? Should it be confined to exploring future options?

5) How can sustainability issues be incorporated in land use analysis and in particular in linear programming models, serving as a tool for such an analysis?

The study presents a linear programming model for analysing land use in a case study, the Neguev settlement in the Atlantic Zone of Costa Rica. The model is a sub-regional model incorporating different farm types. By evaluating different scenarios, land use options are studied.

**Land use planning and land evaluation**

The study starts with a review of land evaluation and land use planning from an economic angle in Chapter 2, while suggestions for improvement are provided in Chapter 4. The economic critique concerns a) the selection of land use types for evaluation, b) the definition of land use types without sufficiently taking into account farm systems of which they form a part, c) the often rather qualitative way of describing the land use types, and d) the definition of suitability levels which are economic in character, as they relate benefits to costs, even for the biophysical part of a land evaluation. The suggestions for improvement are to consider land use types, in combination with land units, as components of farm systems, which leads to the type of land use analysis as outlined in the present study, and to design biophysical suitability definitions for the biophysical part of land evaluation. Then, on the basis of biophysical input and output data, partial budgets per land use system could be prepared. However, economic analysis as such is more relevant and feasible at the farm and (sub-)regional levels of analysis.
Economic theory and land use

Economic theories of land use are reviewed in Chapter 3. Land is defined as an economic resource. After a brief examination of prospects for agricultural production and population growth, and problems of land degradation, the concept of sustainable development is discussed.

After reviewing theories of resource economics, it is concluded that these theories are relevant and provide 'food for thought', but lack direct applicability to more practical cases of land use analysis. Ideas of land economics (e.g. land use as a multidisciplinary study object; views on conservation), concepts of classical economics concerning scarcity and rent, and views on mitigated scarcity of land through the inventiveness of land users induced by the same scarcity (Boserup) are in many instances pertinent, but not always directly applicable. Application of optimal control theories and of theories linking the areas of economy and ecology, although in principle on the right track too, are even more difficult to envisage.

Concepts of cost-benefit analysis and of farm management, production economics and household economics are more directly applicable to land use questions. Cost-benefit analysis supports decisions regarding investment in land or in perennial crops, livestock activities and reforestation. Farm management, production economics and household economics provide insights into questions at the farm level of what, how (including by whom) and when to produce.

Other important or useful concepts originate from regional economics (comparative advantage), or point to institutional problems, in particular questions concerning land tenure and contradictions between different (groups of) land users. Finally, the existence of 'unsolved' problems within economics, like micro-macro linkages, aggregation problems and partial versus general equilibrium analysis, at times highly relevant for land use issues, should caution against undue belief in the ability of the results to mirror reality.

Land use analysis

Apart from making suggestions for improving land evaluation, Chapter 4 also provides an outline for the role of economics within land use analysis. The background of this outline is formed by a skeleton model of the agricultural sector, concepts of regional agricultural planning, in particular a comprehensive resource based approach, and the so-called LEFSA sequence for land use planning. The basic idea is to distinguish levels of analysis and to consider the analyses made by several disciplines
(at least agronomy, soil science and economics) at each of these levels. Furthermore, at each of these levels models can be designed, which are connected in a modular fashion and which foster multi- or interdisciplinary collaboration. The methodology developed here, USTED (Uso Sostenible de Tierras En el Desarrollo, Sustainable Land Use in Development), is an example of such an approach to land use analysis.

At the activity level, crop growth simulation models can be used. However, these are often not (yet) sophisticated enough to provide a satisfactory approach to complicated situations of limited nutrient availability and the incidence of pests and diseases. In the majority of the cases one has to rely on the information of farmers and experts to construct input-output budgets. The activity level models are incorporated into farm and sub-regional models by extracting relevant input and output coefficients from these models. In view of the differences between farms, the development of models per farm type in order to diminish possible aggregation biases is advocated, whereby the farm level is not omitted when a sub-regional model is directly constructed. For this purpose farms need to be grouped into relevant and appropriate farm types. As farm type models represent the decision problem at that level, they should be representative of farm level objective(s), options and constraints. Subsequently, the farm type models can be incorporated into a sub-regional model.

A sub-regional model should be representative of farm level decision making within the context of sub-regional opportunities and constraints, including those created by policy decisions. This is approximated here by building a sub-regional model including the farm type models, with an objective function representing the sum of the objective functions of the farm type models. However, this approach is not without problems. In particular, the collective behaviour resulting from the combination of an objective function is formulated as the sum of the objective functions of each farm type with a constraint at the sub-regional level, a common resource. Such collective behaviour is contrary to the original intention of the model, namely to mimic farm level behaviour within a regional context.

**Linear programming**

In Chapter 5 linear programming as a tool for land use analysis is introduced. It starts by discussing aggregation issues, followed by an extensive discussion of linear programming as a tool for land use
analysis. The chapter ends with a description of the necessary and desirable elements of such linear programming models.

The aggregation issues are threefold: the aggregation bias, the problem whereby variables which are exogenous at the farm level become endogenous at the regional level, and the difficulty of decision making at more than one level. The last issue is circumvented by analysing farm level decision in the light of policy decisions without taking a possible feedback into consideration. The second issue occurs, for example, when input and output prices can no longer be considered independently from their supply or demand. This issue is simplified by assuming that for a sub-region, being a geographical part of a region, in its turn a geographical part of a country, the supply or demand is small in comparison to the (international market for the product in question. The first issue, a possible aggregation bias, is of real concern for modelling land use at the (sub-)regional level.

The aggregation bias of concern here exists because options can be different and resources are available in different proportions at the (sub-)regional level than for each individual farm type. For linear models Day (1963) formulated three conditions for aggregating without bias. The farm type models should have proportional objective function coefficients, the same input and output coefficients, and proportional availability of resources. In actual practice this will never be the case, it can only be approximated. In the model of the case study area, the farm types have the same objective function coefficients, and also the same input and output coefficients by construction. Only the proportional availability of resources is different which is achieved through clustering on the basis of the availability of farm land and labour resources. However, as labour can be exchanged (involving a transaction cost) between farm types, the availability of these resources can become more proportional.

It turns out that the aggregation bias in the optimal solution is very small, less than one percent of the value of the objective function. This is assessed with an aggregate model in which the farm types are collapsed into one sub-regional super farm. In conjunction with this, land use according to such an aggregate model is, at the sub-regional level, also nearly the same as the use according to the original model with five farm types. Thus, under the conditions in the case study, distinguishing farm types is not important regarding overall land use. Nevertheless, the different farm types still provide insight into the distribution of a number of outcomes over the farm types, like income and employment. Furthermore, where farm types have different objective function coefficients (e.g. different prices) or have different land use options (e.g.
economies of scale in cattle production systems) the aggregation bias will be more important. The same applies if the exchange of a resource between farm types is more limited, or demands higher transaction costs.

Linear programming models as a tool for land use analysis are discussed. They are compared to similar models for (regional) agricultural sectors from the early 1970s. It can be concluded that there are many similarities with regard to the use of linear programming as such. However, a major advance of the present model is its use of a methodology or system for land use analysis, including modules for detailed description of land use systems, soil nutrient depletion and a geographical information system. Furthermore, a new element is the use of annuities of present ‘quantities’ over the life-span of the land use systems to calculate the input and output coefficients for use in the linear programming model. In this way land use systems with different life-cycles can be better compared.

Sustainability

The definition of Pearce & Turner (1990: 24) of sustainable development, in combination with their ‘rules’ for resource use, is applied to the issue of sustainable land use, and in particular where a programming model is employed. Maximising the net benefits of economic development is interpreted as having an objective function that maximises the economic surplus, while subject to maintaining the services and quality of natural resources over time is elaborated through the definition of relevant sustainability indicators which can be incorporated as constraints. In that way the first rule for resource use can be applied: (a1) utilise renewable resources at rates less than or equal to the natural rate at which they regenerate, and (a2) keep waste flows to the environment at or below the assimilative capacity of the environment (Pearce & Turner, 1990: 24 & 44). The left hand side of a constraint represents the use of a resource or the amount of pollutant in the environment, while the right hand side indicates the ‘natural rate of regeneration’ of a resource or the ‘assimilative capacity’ of the environment. The second rule for resource use is implied in a (linear) programming set-up. This rule is as follows: (b) optimise the efficiency with which non-renewable resources are used, subject to substitutability between resources and technical progress (Pearce & Turner, 1990: 24). The optimal solution of a programming problem is by definition the most efficient use of the resources, given the objective and the options for resource use. The effects of substitution can be studied through shadow prices and sensitivity analysis. Technical
'progress is part of the model as each land use system is specified for different technologies, including future ones as far as they are known.

REALM for the Neguev

In Chapter 6 the case study area is described, in particular with regard to land use. The specifics of the Neguev area plus the methodological considerations as outlined in Chapter 5 inspired the construction of the Regional Economic Agriculture Land-use Model (REALM) as a case study. The sub-regional land use model REALM has its strengths and limitations. The model is part of a comprehensive methodology for land use analysis (USTED), incorporating a module to store quantitative LUST (Land Use System & Technology) data and linked to a geographical information system. The model is extensive with regard to the technology options for the land use systems considered. Moreover, the location of each land use can be indicated.

Since the model is a linear programming model, it is possible to include many land use systems, each with a number of technological options. Because it is a model at the sub-regional level (incorporating different farm types), it permits a more detailed formulation than models at higher (e.g. regional, national) levels of analysis. Each LUST has fixed technical coefficients, estimated on the basis of farm surveys, expert knowledge and simulation models. Such a quantitative approach is conducive to interdisciplinary research, in this case between agricultural economists, agronomists and soil scientists.

In REALM, (binding) labour constraints have an important impact on land use decisions, for example on the large area with palm heart. This is confirmed by the shadow prices of the monthly labour constraints, which are much higher than the wage rate during several months. Given a certain structure of land units and land use types, the costs and availabilities of factors of production other than land determine the use of land. In this case it concerns labour, but by the same token it could have been capital. The same would apply to other scarce factors or demand constraints. In general, research into the functioning of the labour market (or other relevant markets) should therefore have a high priority in future research regarding the sustainability of land use.

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('supply') within the sub-region is an equilibrium condition of the model. Such conditions or 'system constraints' are also called 'closures' (Robinson, 1989), in this case at the sub-regional level. In the price of labour scenario it can be observed that this type of closure makes the model rather insensitive to changes in wages. Of course, this is also caused by the related feature that labour is both a cost and a benefit in the model. An alternative formulation of the labour market is provided in Appendix 5.

Scenarios

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The base scenario showed possible attractive future land uses. Given yields, input use, and the relative input and output prices, palm heart appears to be an attractive activity. Even if the price were reduced by half, the acreage with this crop would still increase. This result supports the present trend of extending the palm heart cultivation in the Neguev. Needless to say that the realisation of such a scenario outcome would require a thorough analysis of the marketing prospects of palm heart.
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Although it will be arbitrary, it is not too complicated to construct a biocide use index. However, firm statements about the impact of biocides on the environment and about the real assimilative capacity of the environment are very hard to achieve, at least at present. Again, this would be an important research topic. In the biocide reduction scenario of the present study an arbitrary reduction of biocide use of half that of the base scenario is assumed, showing that such a reduction in biocide use is possible with little effect on farm incomes. Moreover, doubling the price of biocides did not affect their use.

A recommendation

It is suggested that the expression land use planning be replace by land use analysis. Land use planning, normally executed at (sub-)regional or higher levels has a tendency to prescribe the 'best' land use, and carries the connotation that decisions can be made about land use at these levels. This is almost never the case. Land use decisions are mostly taken at the farm level. Of course these decisions can be influenced by decisions at the (sub-)regional or national level. Proper decision making at these levels requires a thorough analysis of possible land use decisions at the farm level. Such an analysis is a major aim of land use planning. Therefore, the term land use analysis is preferred to land use planning.
SAMENVATTING

Onderwerp

Sinds een aantal jaren bestaat er bezorgdheid omtrent huidig en toekomstig landgebruik. Is er genoeg land (en water) op aarde om voldoende produkten (voedsel en anderszins) te verschaffen aan een groeiende bevolking en kan daarbij tevens de inkomen van de landbouwbevolking stijgen? Kunnen land en water in de toekomst hun produktievermogen behouden en tevens zorgen voor voldoende leefruimte en natuurschoon? De antwoorden op deze vragen lopen uiteen van pessimistisch (bijvoorbeeld Brown & Kane, 1995) tot optimistisch (bijvoorbeeld Penning de Vries et al., 1995). Het pessimistische antwoord is gebaseerd op het doortrekken van trends met betrekking tot bevolkingsgroei, landbouwproduktie en -productiviteit. Het optimistische antwoord is gebaseerd op een vergelijking van de bevolkingsgroei met potentiële produktiemogelijkheden van land en water voor de verschillende gebieden van de wereld. Landgebruiksanalyse, zoals uiteengezet in de voorliggende studie, zou voor specifieke gebieden een brug kunnen slaan tussen deze benaderingen.


Landevaluatie is vaak de basis voor landgebruiksplanning (FAO, 1993a). Deze laatste kan omschreven worden als de aanwending van land voor verschillend gebruik met het oog op een zo goed mogelijk landgebruik. Zo goed mogelijk wordt meestal bezien vanuit een menselijk of sociaal gezichtspunt, waarbij doeleinden, opties en beperkingen in beschouwing worden genomen.
Deze studie draagt bij aan het zoeken naar een methodologie voor landgebruiksanalyse, gericht op een landgebruik dat voldoende inkomen verschaf aan de landbouwbevolking en tegelijkertijd het produktievermogen van land behoudt.

Het onderzoek richt zich op de volgende vragen.

1) Hoe nuttig zijn de huidige benaderingen binnen landevaluatie en landgebruiksplanning voor het analyseren van landgebruik vanuit een economisch gezichtspunt? En kunnen deze verbeterd worden?

2) Economie is rijk aan theorieën; welke zijn relevant en hoe kan een aantal van deze theorieën gebruikt worden voor het analyseren van landgebruiksproblemen?

3) Wat zijn de belangrijkste elementen van een economische analyse van landgebruik? Hoe kan aan de samenwerking met andere relevante disciplines, zoals agronomie en bodemkunde, vormgeven worden?

4) Wat en hoe is de rol van lineaire programmering binnen een methodologie van landgebruiksanalyse? Moet het gebruik hiervan beperkt blijven tot het exploren van toekomstige opties?

5) Hoe kunnen duurzaamheidsvraagstukken geïncorporeerd worden bij landgebruiksanalyse, in het bijzonder in lineaire programmeringsmodellen die als hulpmiddel dienen voor zo'n analyse?

Deze studie presenteert een lineair programmeringsmodel voor een case-studie, de Neguev nederzetting in de Atlantische Zone van Costa Rica. Het is een sub-regionaal model met verschillende boerenbedrijfstypen. Via het evalueren van verschillende scenario's worden landgebruiksopties bestudeerd.

**Landgebruiksplanning en landevaluatie**

De studie begint in hoofdstuk 2 met een analyse van landevaluatie en landgebruiksplanning vanuit een economisch gezichtspunt. Suggesties voor verbeteringen worden in hoofdstuk 4 gedaan. De economische kritiek op landevaluatie betreft a) de selectie van landgebruikstypen voor evaluatie, b) de definitie van landgebruikstypen zonder voldoende hun plaats en rol binnen de bedrijfssystemen in ogenschouw te nemen, c) de vaak kwalitatieve wijze waarop landgebruikstypen beschreven worden, en d) de definities van geschikheidsniveaus; deze zijn economisch van aard door de vergelijking van baten met kosten, maar worden ook gebruikt voor het biofysische deel van een landevaluatie. De suggesties voor verbetering richten zich op het beschouwen van landgebruikstypen, in combinatie met landeenheden, als componenten van bedrijfssystemen. Dit leidt tot het type landgebruiksanalyse zoals hier besproken. Tevens moeten biofysische geschikheidsdefinities worden opgesteld voor het biofysische deel van landevaluatie. Op basis van biofysische input- en
outputgegevens kunnen dan partiële budgetten worden opgesteld. Echter, een economische beoordeling als zodanig is relevanter en beter mogelijk op bedrijfs- en regionaal niveau.

Economische theorie en landgebruik

Economische theorieën van landgebruik worden besproken in hoofdstuk 4. Land wordt gedefinieerd als een economische hulpbron. Na een korte bespreking van de vooruitzichten voor landbouwproductie en bevolkingsgroei en van problemen rond landdegradatie, wordt het concept duurzame ontwikkeling belicht.

Uit de beschouwing van economische theorieën over het gebruik van hulpbronnen wordt geconcludeerd dat deze theorieën relevant zijn en de gedachtevorming stimuleren, maar dat zij directe toepassingsmogelijkheden in de praktijk ontberen. De denkbeelden van land economics (bijvoorbeeld landgebruik als een multidisciplinair studieonderwerp, visie op conservering), de klassieke economische concepten rond schaarste en grondrente, en de visies op verminderde schaarste aan land door de inventiviteit van landgebruikers, een inventiviteit waar diezelfde schaarste aanleiding toegeeft (Boserup), zijn in vele gevallen ter zake, maar niet altijd direct toepasbaar. Toepassing van optimal control theorieën en theorieën die de economie verbinden met de ecologie, hoewel in principe op het goede pad, zijn nog moeilijker te operationaliseren.

Concepten uit de kosten-baten analyse, de agrarische bedrijfseconomie en de economie van huishoudens zijn directer toepasbaar in landgebruikskwesties. Kosten-baten analyse ondersteunt beslissingen met betrekking tot investeringen in land of in meerjarige gewassen, veehouderij of bosaanplant. Agrarische bedrijfseconomie en de economie van huishoudens geven inzicht in vragen op boerderijniveau rond wat, hoe (inclusief door wie) en wanneer te produceren.

Andere belangrijke en nuttige concepten vinden hun oorsprong in de regionale economie (comparatieve voordelen), of wijzen op institutionele problemen, in het bijzonder op kwesties rond de rechten op land en op tegenstellingen tussen (groepen van) landgebruikers. Tot slot, het bestaan van ‘onopgeloste’ vraagstukken binnen de economische theorie, zoals micro-macro verbanden, aggregatieproblemen en partiële analyses versus algemene evenwichtsmodellen, soms zeer relevant voor landgebruikskwesties, dient ons te behoeden voor een niet gerechtvaardigd geloof in de werkelijkheidswaarde van de resultaten.
Landgebruiksanalyse

Naast het doen van suggesties voor de verbetering van landbeoordeling, geeft hoofdstuk 4 ook een schets van de rol van economie binnen de landgebruiksanalyse. De achtergrond van deze schets wordt gevormd door een schematisch model van de landbouwsector, concepten uit de regionale landbouwplanning, in het bijzonder de comprehensive resource based benadering, en de zogenaamde, stapsgewijze LEFSA procedure voor landgebruiksplanning. De basisgedachte dat er verschillende niveaus van analyse onderscheiden worden en dat op elk niveau de analyses van verschillende disciplines (tenminste: agronomie, bodemkunde en economie) in beschouwing genomen worden. Hiertoe kunnen modellen worden ontwikkeld die op een modulaire wijze verbonden zijn. Deze modellen bevorderen de multi- of interdisciplinaire samenwerking. De methodologie die hier ontwikkeld is, USTED (Uso Sostenible de Tierras En el Desarrollo; Duurzaam landgebruik in het ontwikkelingsproces), is een voorbeeld van zulk een benadering van landgebruiksanalyse.

Gewasgroeimodellen kunnen worden gebruikt op het activiteitsniveau. Echter, deze zijn veelal (nog) niet voldoende realistisch voor het behandelend van gecompliceerde situaties, zoals die waarin nutriënten beperkt beschikbaar zijn of die waarin zich ziekten en plagen voordoen. Bij het maken van input- en outputbudgetten zal men in het merendeel van de gevallen moeten bouwen op de informatie van boeren en experts. De modellen op het activiteitsniveau worden ingebouwd in landbouwbedrijfs- en (sub-)regionale modellen door het overbrengen van relevante input en output coëfficiënten. Met het oog op verschillen tussen bedrijven wordt het aangeraden om modellen per bedrijfstype te ontwikkelen, ten einde een mogelijke aggregatiebias te verminderen, en niet het bedrijfsniveau over te slaan en direct een sub-regionaal model te maken. Bedrijven moeten gegroepeerd worden in relevante en passende bedrijfstypen. Aangezien modellen van bedrijfstypen het beslissingsprobleem op bedrijfsniveau moeten weergeven, moeten deze modellen representatief zijn voor de doeleinden, mogelijkheden en beperkingen op dat niveau. Op hun beurt kunnen modellen van de verschillende bedrijfstypen worden ingebouwd in een sub-regionaal model.

Een sub-regionaal model zou representatief moeten zijn voor beslissingen op bedrijfsniveau binnen de context van sub-regionale mogelijkheden en beperkingen, inclusief beleidsbeslissingen. Dit wordt hier benaderd door het maken van een sub-regionaal model dat is opgebouwd uit modellen van bedrijfstypen. Echter, deze benadering is niet zonder problemen. Een sub-regionaal model vertoont collectief gedrag als gevolg van de combinatie van een doelfunctie die geformuleerd is als de som van de doelfuncties van elk bedrijfstype, met
een gemeenschappelijk beperking op sub-regionaal niveau (**common resource**). Een zodanig collectief gedrag is tegengesteld aan de oorspronkelijke bedoeling van het model, namelijk het weerspiegelen van gedrag op bedrijfsniveau binnen een sub-regionale context.

**Lineaire programmering**

Hoofdstuk 5 begint met een bespreking van aggregatieproblemen in lineaire modellen, gevolgd door een uitgebreide discussie van lineaire programmering als een hulpmiddel voor landgebruiksanalyse. Het hoofdstuk eindigt met een beschrijving van de noodzakelijke en gewenste elementen van zulke lineaire programmeringsmodellen.

De aggregatieproblemen zijn een drietal: de aggregatiebias, het gegeven dat exogene variabelen op het bedrijfsniveau endogeen kunnen worden op regionaal niveau, en de moeilijkheid van besluitvorming op meer dan één niveau. Dit laatste probleem wordt omzeild door beslissingen op bedrijfsniveau te analyseren in het licht van beleidsbeslissingen, zonder een mogelijke terugkoppeling te beschouwen. Het tweede probleem ontstaat bijvoorbeeld als niet langer verondersteld mag worden dat output- en inputprijzen onafhankelijk zijn van het aanbod (output) of de vraag (input). Dit probleem wordt vereenvoudigd door te veronderstellen dat voor een *sub-regio*, zijnde een geografisch deel van een regio die op haar beurt weer een geografisch deel is van een land, het aanbod van outputs en de vraag naar inputs *klein* is in vergelijking met de (inter)nationale markt voor deze produkten of produktiefactoren. Het eerste aggregatieprobleem, de aggregatiebias, kan een belangrijk vraagstuk zijn voor het modelleren van landgebruik op (sub-)regionaal niveau.

De aggregatiebias ontstaat doordat op (sub-)regionaal niveau zich andere mogelijkheden voordoen, en/of de hulpbronnen in een andere verhouding beschikbaar zijn, dan voor ieder bedrijfstype afzonderlijk. Day (1963) formuleerde voor lineaire modellen drie voorwaarden waaronder een aggregatie zonder afwijking mogelijk is. De bedrijfstopen moeten evenredige doelfunctiecoëfficiënten hebben, dezelfde input- en outputcoëfficiënten en een evenredige beschikbaarheid van hulpbronnen. In de praktijk kan deze situatie alleen maar benaderd worden. In het model voor de case-studie hebben de bedrijven dezelfde doelfunctiecoëfficiënten en ook dezelfde input- en outputcoëfficiënten toegestemd gekregen. De beschikbaarheid van hulpbronnen is niet evenredig (ook dit is bewust ingebouwd doordat de onderscheiden bedrijfstopen voortkomen uit een clustering-procedure op basis van de beschikbaarheid van land en arbeid). Echter, doordat arbeid kan worden uitgewisseld tussen bedrijven (tegen transactiekosten) kan de beschikbaarheid van hulpbronnen proportioneler worden.
Samenvatting

Het blijkt dat de aggregatiebias in de optimale oplossing erg klein is, minder dan één procent van de waarde van de doelfunctie. Deze uitkomst is bepaald met behulp van een sub-regionaal model waarin de bedrijfstypen zijn samengevoegd tot één sub-regionaal superbedrijf. Het blijkt ook dat het landgebruik volgens dit geaggregeerde model op sub-regionaal niveau niet verschilt van het landgebruik volgens het oorspronkelijke model met vijf bedrijfstypen. Dus onder de omstandigheden die in de case-studie gelden, is het onderscheiden van bedrijfstypen niet belangrijk voor het bepalen van landgebruik op nederzettingsniveau. Het onderscheid in bedrijfstypen verschaf echter wel inzicht in de verdeling van een aantal variabelen over bedrijven, zoals inkomen en werk. Bovendien zal in het geval dat de bedrijfstypen verschillende doelfunctiecoëfficiënten hebben (bijvoorbeeld verschillende prijzen) of verschillende landgebruiksopties (bijvoorbeeld door schaalverschillen in de extensieve veehouderij) de aggregatiebias wel belangrijk kunnen zijn. Hetzelfde is het geval als de uitwisseling van hulpbronnen tussen bedrijfstypen moeilijker is of hogere transactiekosten vereist.

Voor de bespreking van lineaire modellen als hulpmiddel voor landgebruiksplanning worden deze vergeleken met soortgelijke modellen die sinds de zeventiger jaren gebruikt worden voor de analyse van (regionale) landbouwsectoren. Geconcludeerd wordt dat er veel overeenkomsten bestaan in het gebruik van lineaire programmering als zodanig. Nieuw bij het hier gepresenteerde model is dat het deel uitmaakt van een methodologie of een systeem van landgebruiksanalyse, inclusief modules voor de gedetailleerde beschrijving van landgebruikssystemen, voor bodemnutriëntenverlies en voor een geografisch informatiesysteem.

Voortbouwend op Erenstein & Schipper (1993), is het gebruik van annuïteiten op basis van huidige ‘hoeveelheden’, berekend over de levenscyclus van meerjarige gewassen, een vernieuwing die een betere vergelijking tussen landgebruikssystemen met een verschillende duur mogelijk maakt.

Duurzaamheid

De definitie van duurzame ontwikkeling van Pearce & Turner (1990: 24) wordt, in combinatie met hun ‘regels’ voor het gebruik van natuurlijke hulpbronnen, wordt toegepast op het vraagstuk van duurzaam landgebruik; in het bijzonder indien een lineair programmeringsmodel wordt gebruikt. Maximising the net benefit of economic development wordt geïnterpreteerd als het nastreven van een zo hoog mogelijk economisch surplus (doelfunctie), terwijl subject to maintaining the services and quality of natural resources over time uitgewerkt wordt door
het definiëren van relevante duurzaamheidsindicatoren, die ingebracht kunnen worden als beperkingen in het model. Op die manier kan de eerste regel voor het gebruik van een natuurlijke hulpbron worden toegepast: a1) *utilise renewable resources at rates less than or equal to the natural rate at which they regenerate* en a2) *keep waste flows to the environment at or below the assimilative capacity of the environment* (Pearce & Turner, 1990: 24 & 44). In lineaire programmeringstermen is de *linkerkant* van een beperking representatief voor het gebruik van een hulpbron, of voor de hoeveelheid van een vervuilende stof, terwijl de *rechterkant* indicatief is voor de natuurlijke snelheid waarmee de hulpbron regenerereert, of voor de opname-capaciteit van de omgeving. De tweede regel voor het gebruik van natuurlijke hulpbronnen zit impliciet in de opzet van (lineaire) programmering. Deze regel is als volgt: (b) *optimise the efficiency with which non-renewable resources are used, subject to substitutability between resources and technical progress* (Pearce & Turner, 1990: 24). Gegeven de doelstelling en de opties voor het gebruik, geeft de optimale oplossing van een programmeringsprobleem per definitie het meest efficiënte gebruik van hulpbronnen. De effecten van substitutie kunnen worden bestudeerd met behulp van schaduwprijzen en door middel van gevoeligheidsanalyse. Technische vooruitgang is deel van het model daar waar landgebruikssystemen worden gespecificeerd voor verschillende technologieën, inclusief toekomstige technologieën, voorzover deze bekend zijn.

**REALM voor de Neguev**

In hoofdstuk 6 wordt het gebied van de *case* studie beschreven, met name wat betreft landgebruik. Het specifieke van de Neguev en de methodologische overwegingen zoals besproken in hoofdstuk 5 hebben geleid tot het landgebruiksmodel REALM (*Regional Economic Agriculture Land-use Model*; Regionaal Economisch Landbouwmodel voor Landgebruik) als een case-studie. Het sub-regionale landgebruiksmodel REALM heeft zowel sterke kanten en als beperkingen. Het model is deel van een veelomvattende methodologie voor landgebruiksanalyse (USTED), met een module voor het opslaan van kwantitatieve LUST (*Land Use System & Technology*; Landgebruikssystemen met een gespecificeerde technologie) gegevens en dat verbonden is met een geografisch informatiesysteem. Het model bevat vele technologische opties voor de bekeken landgebruikssystemen. Bovendien kan de locatie van elk landgebruik worden aangegeven.

Omdat het model een lineair programmeringsmodel is, is het mogelijk om veel verschillende landgebruikssystemen te onderscheiden, ieder met een aantal technologische varianten. Omdat het een model is op *sub-
regionaal niveau (dat opgebouwd is uit sub-modellen voor verschillende bedrijfstypen), is een meer gedetailleerde formulering mogelijk dan bij modellen op hogere analyse niveaus (bijvoorbeeld op regionaal of nationaal niveau). Elke LUST heeft vaste technische coëfficiënten, die geschat zijn op basis van onderzoek onder de boerenbedrijven, op basis van kennis van deskundigen en van simulatiemodellen. Zulk een kwantitatieve benadering is behulpzaam bij interdisciplinair onderzoek, in dit geval tussen agronomen, bodemkundigen en landbouweconomen.

In REALM hebben (bindende) arbeidsbeperkingen een belangrijke weerslag op landgebruiksbeslissingen, bijvoorbeeld op het grote areaal met palmbhart. Dit wordt bevestigd door de schaduwprijzen van de maandelijkse arbeidsbeperkingen, die in een aantal maanden veel hoger zijn dan de loonvoet. Gegeven een zekere structuur van landeenheden en landgebruikstypen, bepalen de kosten en beschikbaarheid van andere produktiefactoren dan land het gebruik van land. In het geval van de Neguev is dit arbeid, maar voor hetzelfde geld zou het kapitaal hebben kunnen zijn. Hetzelfde geldt voor andere schaarse factoren of marktbeperkingen. In het algemeen kan gesteld worden dat onderzoek naar het functioneren van de arbeidsmarkt (of andere relevante markten) een hoge prioriteit zou moeten hebben bij toekomstig onderzoek naar duurzaam landgebruik.

Omdat het model sub-matrices voor elk bedrijfstype omvat, benadert het de beschikbaarheid van hulpbronnen op bedrijfsniveau, in plaats van de beschikbaarheid op geaggregeerd sub-regionaal niveau. Toch worden de bedrijfstypen niet los van elkaar geoptimaliseerd, omdat elk type rekening moet houden met het aanbod van en de vraag naar arbeid. Het gelijksstellen van de vraag naar inhuur-arbeid van alle bedrijfstypen tezamen, met de som van het aanbod van arbeid van alle bedrijfstypen (arbeid buiten het eigen bedrijf, maar binnen de Neguev), is een evenwichtsconditie van het model. Zulke condities worden system constraints of closures genoemd (Robinson, 1989), in dit geval op het sub-regionale niveau. In het price of labour scenario kan waargenomen worden dat zo’n ‘sluiting’ het model nogal ongevoelig voor veranderingen in lonen maakt. Dit hangt natuurlijk samen met het daaraan gerelateerde verschijnsel dat arbeid zowel een kost als een baat is in het model. Een alternatieve formulering van de arbeidsmarkt wordt gegeven in appendix 5.

Scenario’s

In hoofdstuk 7 worden scenario’s van mogelijk landgebruik geanalyseerd. De scenario’s zijn gerelateerd aan mogelijke beleidsmaatregelen met betrekking tot duurzaamheidsindicatoren of aan mogelijke ontwikkelingen met betrekking tot factoren die landgebruik beïnvloeden. De volgende
scenario's zijn bekeken (Engelse namen): biocide reduction, biocide price, soil nutrient depletion, price of palm heart, price of labour and discount rate scenario's. De resultaten van deze scenario's worden vergeleken met de resultaten van een base scenario ten einde de effecten van milieumaatregelen of van veranderingen in landgebruik beïnvloedende factoren te bestuderen. In alle scenario's is het economisch surplus de doelfunctie.

Het bestuderen van scenario's kan gezien worden als een verkenning van mogelijke ontwikkelingen, ervan uitgaande dat landgebruiksbeslissingen op bedrijfsniveau door één doelstelling bepaald worden. Dit in tegenstelling tot verkenningen met meervoudige lineaire doelprogrammeringsmodellen voor landgebruiksanalyse, waar de oplossingsruimte gevormd wordt door verschillende doeleinden. Door deze modellen, na elkaar, op te lossen voor de verschillende doeleinden, kan men een Pareto-optimale oplossingsruimte verkrijgen. In zo'n ruimte kan een doel alleen vergroot worden ten koste van één of meerdere andere doeleinden. De mogelijke oplossingsruimte van een meervoudig doelprogrammeringsmodel voor de Neguev zou verschillend zijn van de ruimte die verkregen is met de huidige versie van REALM. Met het oog op de analyse van oplossingen gestuurd door een economisch plausibel doel, namelijk een zo groot mogelijk economisch surplus op bedrijfsniveau, is REALM te prefereren boven een meervoudig doelprogrammeringsmodel, omdat REALM door zijn doelfunctie relevanter is voor het bestuderen van de effecten van veranderende omstandigheden of van beleidsmaatregelen op landgebruik en daaraan gerelateerde variabelen.

Het base scenario laat mogelijk aantrekkelijk toekomstig landgebruik zien. Gegeven de opbrengsten, het inputgebruik en de relatieve input- en outputprijzen, is palmhart een aantrekkelijk gewas. Zelfs als de prijs zou halveren, dan nog zou het oppervlak toenemen ten opzichte van het huidige areaal. Dit resultaat spoort met de huidige trend in het palmhart-areaal in de Neguev. Onnodig te zeggen dat het realiseren van zo'n scenario een grondige analyse van de marketingmogelijkheden vereist.

Karakteristiek voor het model is dat duurzaamheid wordt geanalyseerd met betrekking tot twee indicatoren, bodemnutriëntenverlies en biocidegebruik. Deze zijn de meest relevante indicatoren, gezien de omstandigheden in de Neguev. Het schatten van de nutriëntenverlies als stroomvariabele voor elke LUST is, hoewel niet eenvoudig, goed mogelijk. Echter het schatten van de voorraad nutriënten in de bodem en het aannemen van een periode waarbinnen het verlies de produktie van de LUST niet aantast, is veel lastiger. Het aangeven van limieten voor het gebruik van natuurlijke hulpbronnen, waar mogelijk verbonden met het idee van de natuurlijk regeneratiesnelheid, is daarom een belangrijk toekomstig –interdisciplinair- onderzoeksthema. Bovendien heeft in het
huidige model verlies aan bodemvruchtbaarheid door nutriëtenverlies geen effect op de opbrengst per ha van een landgebruik. Dit zou wel bereikt kunnen worden via lange-termijn LUSTen, die de effecten van een verminderde vruchtbaarheid kunnen meenemen, of door het model dynamisch te maken. Het soil nutrient depletion scenario laat overigens zien dat een mogelijke restrictie van dit verlies, op het niveau van landeenheden binnen bedrijfstypen, slechts een geringe invloed heeft op de inkomens van de bedrijfsten.

Hoewel arbitrair, hoeft de constructie van een biocidegebruiksindex niet te ingewikkeld te zijn. Niettemin, zijn gefundeerde uitspraken over de gevolgen van biociden voor het milieu en over de werkelijke opnamecapaciteit van de omgeving erg moeilijk te verkrijgen, tenminste tot nu toe. Dit is een belangrijk onderwerp voor verder onderzoek. Het biocide reduction scenario van de onderhavige studie laat zien dat een afname van het biocidegebruik tot de helft van het gebruik in het base scenario, slechts een gering effect heeft op de inkomens van de bedrijfsten. Bovendien heeft het verdubbelen van de prijzen van biociden geen effect op het gebruik van deze middelen.

Een aanbeveling

Het gebruik van de uitdrukking landgebruiksplanning wordt afgeraden. De term landgebruiksanalyse heeft de voorkeur. Landgebruiksplanning, die normaal gesproken uitgevoerd wordt op (sub-)regionaal niveau of hoger, heeft de neiging om het ‘beste’ landgebruik voor te schrijven; tevens doet deze term het voorkomen alsof landgebruiksbeslissingen op dat niveau genomen kunnen worden. Dat is bijna nooit het geval. Beslissingen omtrent landgebruik worden op boerenbedrijfsniveau genomen. Natuurlijk kunnen deze laatste beslissingen wel beïnvloed worden door beslissingen op (sub-)regionaal of nationaal niveau. Goede beslissingen op deze beleidsniveaus vereisen een grondige analyse van mogelijke landgebruiksbeslissingen op bedrijfsniveau. Zo’n analyse is het hoofddoel van landgebruiksplanning. Daarom is landgebruiksanalyse een betere term dan landgebruiksplanning.
RESUMEN

Tema

Últimamente una serie de preocupaciones han dominado la agenda sobre el uso presente y futuro de la tierra. ¿Son los recursos del planeta capaces de suministrar suficientes productos (alimento y otros) para sostener una población en aumento y brindar ingresos crecientes a la población agrícola? ¿Pueden los recursos de la tierra y el agua mantener su capacidad productiva a través del tiempo, brindar suficiente espacio para vivir, y ofrecer amenos servicios? Las respuestas a estas preguntas oscilan entre el pesimismo (p.e. Brown & Kane, 1995) y el optimismo (p.e. Penning de Vries et al., 1995). La respuesta pesimista está basada principalmente en extrapolar tendencias actuales sobre el crecimiento de la población y de la producción agrícola y productividad, mientras que la optimista está basada en comparar tendencias de población con aquello que potencialmente podría ser producido con los recursos de la tierra y el agua en diferentes regiones del mundo. El análisis de uso de la tierra que se desarrolla en el presente estudio podría salvar la distancia entre estos dos enfoques en áreas particulares.

Desde los tiempos de Ricardo y Malthus una preocupación explícita de los economistas ha sido los problemas de alimentar a la población de áreas diferentes y, por consecuencia, del uso de la tierra. Dentro de la economía, la economía de la tierra (land economics) se desarrolló como una rama especial, que estudió el uso de recursos de la tierra desde diferentes perspectivas. Hoy día, el estudiar el uso de la tierra es parte de la economía agrícola.

Obviamente, el uso de la tierra es también el foco de atención de disciplinas más técnicas como la agronomía y la edafología. Como resultado, se desarrolló una rama separada de estudio que involucró una valoración multidisciplinaria de la capacidad de la tierra para diferentes usos, usualmente llamada evaluación de la tierra (FAO, 1976 & 1983). Dent & Young (1981: 115) describen la evaluación de la tierra como "el proceso de estimar el potencial de la tierra para formas de uso alternativo". Idealmente, tal valoración incorpora también aspectos económicos y sociales.

La evaluación de la tierra es usualmente la base para la planificación del uso de la tierra (FAO, 1993a). Esta última puede ser holgadamente descrita como la asignación de diferentes unidades de tierra para usos diferentes, buscando el mejor uso de la tierra. Lo ‘mejor’ usualmente se
mira desde un punto de vista humano, involucrando objetivos, opciones y restricciones.

El presente estudio contribuye a la búsqueda de una metodología para el análisis del uso de la tierra, apuntando a un uso de la tierra que brinde suficientes (y crecientes) ingresos a la población agrícola manteniéndose al mismo tiempo la capacidad productiva de la tierra. En particular el estudio está enfocado hacia el papel del análisis económico, haciendo referencia a las siguientes preguntas principales de investigación.

1) ¿Qué tan útiles son los enfoques actuales dentro de la evaluación de la tierra y la planificación del uso de la tierra desde un punto de vista económico? ¿Hasta qué punto pueden ser mejorados?

2) La economía es rica en diferentes teorías; ¿cuáles son relevantes y cómo pueden estas teorías ser usadas para analizar asuntos del uso de la tierra?

3) ¿Cuáles son los elementos principales de un análisis económico de uso de la tierra? ¿Qué forma debería tener la colaboración con otras disciplinas relevantes como la agronomía y edafología?

4) ¿Cuál es el papel de la programación lineal dentro de una metodología para el análisis del uso de la tierra? ¿Debería ser confinado al análisis de opciones futuras?

5) ¿Cómo pueden ser incorporados problemas de sostenibilidad en el análisis del uso de la tierra y en particular en modelos de programación lineal, a tal cabo que estos sirvan como herramienta de análisis?

El estudio presenta un modelo de programación lineal para el análisis del uso de la tierra en un estudio de caso, el asentamiento del Neguev en la Zona Atlántica de Costa Rica. El modelo es un modelo subregional que incorpora diferentes tipos de fincas. Mediante la evaluación de diferentes escenarios se estudian diferentes opciones de uso de la tierra.

Planificación del uso de la tierra y evaluación de la tierra

El estudio comienza pasando revista a la evaluación de la tierra y la planificación del uso de la tierra desde un ángulo económico en el Capítulo 2, mientras que sugerencias para el mejoramiento se brindan en el Capítulo 4. La crítica económica concierne a) la selección de tipos de uso de la tierra para evaluación, b) la definición de los tipos de uso de la tierra sin tomar suficientemente en cuenta los sistemas de finca de los cuales forman parte, c) la tendencia a describir los tipos de uso de la tierra de manera cualitativa, y d) la definición de niveles de aptitud que son de carácter económico puesto que relacionan beneficios con costos, incluyendo la parte biofísica de la evaluación de la tierra. Para un mejoramiento se sugiere considerar los tipos de uso de la tierra, en combinación con unidades de tierra, como componentes de los sistemas
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de finca. Esto lleva al tipo de análisis de uso de la tierra tal y como se expresa en el presente estudio, así como al diseño de definiciones de aptitud biofísica para la parte biofísica de la evaluación de la tierra. Sobre esta base de datos biofísicos de insumo y producto se podrían preparar presupuestos parciales por sistema de uso de la tierra. Sin embargo, el análisis económico como tal es más relevante y viable a los niveles de análisis de finca y (sub)regional.

Teoría económica y uso de la tierra

En el Capítulo 3 se repasan las teorías económicas de uso de la tierra. La tierra se define como un recurso económico. Después de un breve examen de los prospectos para la producción agrícola y el crecimiento de la población, y de los problemas de la degradación de la tierra, se discute el concepto de desarrollo sostenible.

Después de examinar las teorías de la economía de los recursos, se concluye que éstas son relevantes y que brindan ideas retos, pero carecen de aplicación directa en casos más prácticos sobre análisis de uso de la tierra. Ideas de la economía de la tierra (p.e. el uso de la tierra como un objeto de estudio multidisciplinario; enfoques sobre conservación), conceptos de economía clásica sobre escasez y renta, y enfoques sobre escasez mitigada de tierra a través de la inventiva de los propios usuarios de la tierra e inducida por la misma escasez (Boserup), son pertinentes en muchas casos pero no siempre directamente aplicables. La aplicación de teorías de control óptimo y de teorías que ligan la economía y la ecología pueden ser potencialmente útiles, pero son difíciles de contemplar en la práctica.

De mayor aplicación para preguntas del uso de la tierra son los conceptos del análisis de costo-beneficio, administración rural, economía de la producción y economía para el hogar. El análisis de costo-beneficio apoya las decisiones referentes a inversiones en tierra, en cultivos perennes, en actividades de ganadería y en reforestación. La administración rural, la economía de la producción y la economía del hogar brindan conocimiento sobre preguntas a nivel de finca sobre qué, quiénes, cómo y cuándo producir.

Otros conceptos importantes y útiles se originan en la economía regional (ventajas comparativas), o apuntan a problemas institucionales, en particular preguntas sobre tenencia de la tierra y contradicciones entre diferentes (grupos de) usuarios de la tierra. Finalmente, la existencia de problemas no resueltos dentro de la economía, tales como los vínculos micro-macro, problemas de agregación, o el análisis de equilibrio parcial versus general, y los cuales pueden en ocasión ser altamente relevantes en asuntos de uso de la tierra, deberían prevenírnos contra la certeza de que los resultados reflejan la realidad.
Análisis del uso de la tierra

Aparte de hacer sugerencias para mejorar la evaluación de la tierra, el Capítulo 4 también brinda un esquema del papel de la economía dentro del análisis del uso de la tierra. Los antecedentes de este esquema están formados por un modelo esqueleto del sector agrícola, conceptos de planificación agrícola regional - en particular un enfoque comprensivo basado en los recursos - y la así llamada secuencia LEFSA para la planificación del uso de la tierra. La idea básica es distinguir los niveles de análisis así como considerar los análisis planeados por diferentes disciplinas (por lo menos agronomía, edafología y economía) en cada uno de estos niveles. Además, en cada uno de estos niveles se pueden diseñar modelos, conectados de manera modular y que fomentan la colaboración multi- o interdisciplinaria. La metodología desarrollada aquí, USTED (Uso Sostenible de Tierras En el Desarrollo), es un ejemplo de tal enfoque en el análisis de uso de la tierra.

A nivel de actividad, se pueden usar modelos de simulación de crecimiento de cultivos. Sin embargo, estos no son (aún) lo suficientemente sofisticados para aproximar de manera satisfactoria situaciones complicadas de disponibilidad limitada de nutrientes y la incidencia de enfermedades y plagas. En la mayoría de los casos uno tiene que confiar en la información de agricultores y expertos para construir presupuestos de insumo-producto. Los modelos a nivel de actividad están incorporados en modelos de finca y subregionales debido a su extracción de coeficientes de insumo y producto. En vista de las diferencias entre las fincas, se propone desarrollar modelos por tipo de finca. De esta manera se reducen posibles sesgos de agregación que se obtendrían en la construcción directa de un modelo subregional. Por tanto, las fincas necesitan ser agrupadas en tipos de fincas relevantes y apropiados. Como los modelos de tipo de finca representan el problema de decisión a ese nivel, deberían ser representativos de los objetivos, las opciones y las restricciones a nivel de finca. Subsecuentemente, los modelos de tipo de finca pueden ser incorporados en un modelo subregional.

Un modelo subregional debería ser representativo del nivel de toma de decisiones en la finca dentro del contexto de oportunidades y restricciones subregionales, incluyendo aquellas creadas por decisiones de políticas económicas. Esto se aproxima aquí a través de la elaboración de un modelo subregional que incluye los modelos de tipo de finca, con una función objetiva formulada como la suma de las funciones objetivas de cada tipo de finca. Sin embargo, este enfoque no está libre de problemas. En particular, la conducta colectiva que resulta de la combinación de una función objetiva formulada como la suma de las funciones objetivas de cada tipo de finca con una restricción en el nivel subregional, un recurso
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en común. Tal conducta colectiva es contraria a la intención original del modelo, la cual es imitar el comportamiento a nivel de finca dentro de un contexto regional.

Programación lineal

En el Capítulo 5 se introduce la programación lineal como una herramienta para el análisis del uso de la tierra. El capítulo comienza con la discusión de aspectos de agregación, seguida por una extensa discusión de la programación lineal como una herramienta para el análisis de uso de la tierra. El capítulo finaliza con una descripción de los elementos necesarios y deseables de tales modelos de programación lineal.

Los aspectos de agregación consisten de tres dimensiones: el sesgo de agregación, el problema de que las variables exógenas a nivel de finca se tornan endógenas a nivel regional, y la dificultad de la toma de decisiones a más de un nivel. El último asunto es evadido analizando la decisión al nivel de finca a la luz de las decisiones de política sin tomar en cuenta una posible retroalimentación. El segundo asunto ocurre, por ejemplo, cuando los precios de productos e insumos no pueden seguir considerándose como independientes de su oferta o demanda. Este asunto se simplifica asumiendo que para una subregión, por ser parte geográfica de una región, y a su vez una parte geográfica de un país, la oferta o demanda es pequeña en comparación con el mercado (inter)nacional para el producto en cuestión. El primer aspecto, un posible sesgo de agregación, es de importancia real para modelar el uso de la tierra a nivel (sub)regional.

El sesgo de agregación es de importancia debido a que a nivel (sub)regional las opciones pueden ser diferentes y los recursos están disponibles en diferentes proporciones que para cada tipo de finca individual. Para modelos lineales Day (1963) formuló tres condiciones para agregar sin sesgo. Los modelos de tipos de finca deberían tener coeficientes de funciones objetivas proporcional, los mismos coeficientes de insumo y producto, y disponibilidad proporcional de recursos. En la práctica este nunca será el caso, pero puede aproximarse. En el modelo del área del estudio de caso, el propósito es que cada tipo de finca tenga los mismos coeficientes de la función objetiva, y también los mismos coeficientes de insumo-producto. Solamente la disponibilidad proporcional de los recursos es diferente, lo cual se obtiene a través de una agrupación en base a la disponibilidad de tierra agrícola y recursos de mano de obra. Sin embargo, como la mano de obra puede ser intercambiada (lo cual involucra un costo de transacción) entre los tipos de finca, la disponibilidad de estos recursos puede volverse más proporcional.
Resulta que el sesgo de agregación es muy pequeño en la solución óptima (menos del uno por ciento del valor de la función objetiva). Esto es evaluado con un modelo agregado en el cual los tipos de finca son juntados dentro de una super finca subregional. En conjunció con esto, el uso de la tierra en el modelo agregado es, a nivel subregional, casi el mismo que el uso de la tierra según el modelo original con cinco tipos de finca. Así, bajo las condiciones en el estudio de caso, no es importante distinguir los tipos de finca en relación con el uso global de la tierra. A pesar de eso, los diferentes tipos de finca todavía aportan nociones sobre la distribución de un cierto número de resultados que se relacionan con los tipos de finca, tales como el ingreso y el empleo. Además, el sesgo de agregación será más importante en caso de que los tipos de finca tengan diferentes coeficientes en su función objetiva (p.e. precios diferentes) o tengan diferentes opciones de uso de la tierra (p.e. economías de escala en sistemas de producción ganadera). Lo mismo aplica si el intercambio de un recurso entre los tipos de finca es más limitado, o demanda costos de transacción más altos.

Se discuten los modelos de programación lineal como herramienta para el análisis de uso de la tierra. Estos se comparan con modelos similares para sectores agrícolas (regionales) existentes al comienzo de los años setenta. Se puede concluir que hay muchas similitudes con respecto al uso de la programación lineal como tal. Sin embargo, un avance importante del presente modelo es el uso de una metodología para el análisis de la tierra, incluyendo módulos para la descripción detallada de los sistemas de uso de la tierra, el agotamiento de los nutrientes del suelo así como un sistema de información geográfica. Además, un nuevo elemento es el uso de anualidades de las ‘cantidades’ presentes en el periodo de vida de los sistemas de uso de la tierra para calcular los coeficientes de insumo y producto a usar en el modelo de programación lineal. De esta manera los sistemas de uso de la tierra con diferentes ciclos de vida pueden compararse mejor.

Sostenibilidad

La definición de Pearce & Turner (1990: 24) de desarrollo sostenible, en combinación con sus 'reglas' para el uso de recursos es aplicada al tema de uso sostenible de la tierra, y en particular en caso de empleo de un modelo de programación lineal. El maximizar los beneficios netos del desarrollo económico se interpreta como tener una función objetivo que maximice el excedente económico, sujeto a mantener los servicios y la calidad de los recursos naturales a través del tiempo se elabora en base a la definición de los indicadores relevantes de sostenibilidad que pueden ser incorporados como restricciones. De esa manera, la primera regla para el uso de los recursos puede ser aplicada: a1) utilice los recursos
renovables a tasas menores o iguales a la tasa natural a la cual se regeneran, y a2) mantenga los flujos de desecho al ambiente iguales o menores a la capacidad de asimilación del ambiente (Pearce & Turner, 1990: 24 & 44). El lado izquierdo de una restricción es representativo para el uso de un recurso o de la cantidad de contaminante al ambiente, mientras que el lado derecho indica la ‘tasa natural de regeneración’ de un recurso o la ‘capacidad asimiladora del ambiente’. La segunda regla para el uso de recursos está implícita en un marco de programación (lineal). Esta regla dice: b) optimise la eficiencia con la cual los recursos no renovables son usados, sujeto a la sustitutabilidad entre los recursos y al progreso tecnológico (Pearce & Turner, 1990: 24). La solución óptima de un problema de programación es por definición el uso más eficiente de los recursos, dado el objetivo y las opciones para el uso de los recursos. Los efectos de sustitución pueden ser estudiados via precios de sombra y análisis de sensibilidad. El progreso tecnológico es parte del modelo ya que cada sistema de uso de la tierra se especifica para diferentes tecnologías, incluyendo futuras tecnologías en la medida en que estas se conozcan.

**REALM para el Neguev**

En el Capítulo 6 se describe el área del estudio de caso, en particular en lo referente al uso de la tierra. Los detalles del área del Neguev junto con las consideraciones metodológicas expuestos en el Capítulo 5 inspiraron la construcción del Modelo Económico Agropecuario Regional de Uso de la Tierra (siglas en inglés REALM, *Regional Economic Agriculture Land- use Model*) para el estudio de caso. El modelo de uso de la tierra subregional REALM tiene sus fortalezas y limitaciones. El modelo es parte de una metodología comprensiva para el uso de la tierra (USTED), incorporando un módulo para almacenar datos de los LUST (Sistema y Tecnología de uso de la Tierra) y ligado a un sistema de información geográfica. El modelo es extensivo con respecto a las opciones tecnológicas para los sistemas de uso de la tierra que se consideran. Además, permite la localización de cada tipo de uso de la tierra.

Debido a que el modelo es un modelo de programación lineal, es posible incluir muchos sistemas de uso de la tierra, cada uno con un cierto número de opciones tecnológicas. Puesto que también es un modelo a nivel subregional (incorporando diferentes tipos de finca), permite una formulación más detallada que modelos a niveles más altos (p.e. regional, nacional) de análisis. Cada LUST tiene coeficientes técnicos fijos, estimados sobre la base de encuestas a agricultores, conocimiento de expertos y modelos de simulación. Tal enfoque cuantitativo conduce a la investigación interdisciplinaria, en este caso entre economistas agrícolas, agrónomos y edafólogos.
En REALM, restricciones (vinculantes) de mano de obra tienen un impacto importante en las decisiones de uso de la tierra, por ejemplo en la extensa área con palmito. Esto se confirma con los precios de sombra de las restricciones mensuales de mano de obra, que son mucho más altos que la tasa de salarios de varios meses. Dada una cierta estructura de unidades de tierra y de tipos de uso de tierra, los costos y disponibilidades de otros factores de producción que no son tierra determinan el uso de la misma. En este caso se refiere a la mano de obra pero por la misma razón pudo haber sido capital. Lo mismo aplicaría a otros factores escasos o a restricciones en la demanda. En general, la investigación del funcionamiento del mercado de mano de obra (u otros mercados relevantes) debería tener alta prioridad en investigaciones futuras relacionadas con la sostenibilidad del uso de la tierra.

Puesto que el modelo contiene submatrices para cada tipo de finca dentro de la subregión, este aproxima las disponibilidades de recursos al nivel de finca, en vez de los recursos agregados. A la vez, los tipos de finca no son optimizados aisladamente puesto que cada tipo de finca tiene que tomar en cuenta la oferta y demanda de mano de obra subregional. La ecuación entre la disponibilidad del trabajo contratado en todos los tipos de finca ('demanda') y la mano de obra de fuera de la finca en todos los tipos de finca ('oferta') dentro de la subregión, es una condición de equilibrio del modelo. Tales condiciones, o 'restricciones del sistema', también son llamadas 'clausuras' (closures; Robinson, 1989), en este caso a nivel subregional. En el escenario del precio de la mano de obra puede observarse que este tipo de 'clausura' hace al modelo bastante insensible a los cambios en salarios. Obviamente, esto también es causado por la característica de que la mano de obra es tanto un costo como un beneficio en el modelo. Una formulación alternativa del mercado de mano de obra se brinda en el Apéndice 5.

Escenarios

En el Capítulo 7 se analizan los escenarios referentes a posibles usos de la tierra. Los escenarios se refieren a medidas de política relacionadas con los indicadores de sostenibilidad o con avances en lo referente a los factores determinantes del uso de la tierra. Los escenarios incluyen reducción de biocidas, precio de biocidas, agotamiento de los nutrientes del suelo, precio del palmito, precio de la mano de obra y la tasa de descuento. Los resultados de estos escenarios se comparan con los resultados de un escenario base para estudiar los efectos de políticas ambientalistas o de cambios en los factores determinantes del uso de la tierra. En todos los escenarios la función objetiva es el excedente económico.
Estudiar los escenarios puede verse como un reconocimiento de posibles eventos, dado el supuesto de que es un solo objetivo el que determina las decisiones de uso de la tierra a nivel de finca. Esto contrasta con reconocimientos en modelos de programación lineal de múltiples metas (PLMM) para el análisis de uso de la tierra en el cual el espacio de la solución está formado por diferentes objetivos. Solucionando subsecuentemente tal modelo para los diferentes objetivos, uno puede obtener un espacio de solución Pareto óptimo en el cual un objetivo solamente puede incrementarse a expensas de otro objetivo. El espacio de solución posible de un modelo PLMM para el área del Neguev sería diferente del obtenido con el actual modelo REALM del Neguev. Desde el punto de vista de tratar de investigar soluciones manejadas por un objetivo económicamente plausible, se prefiere el presente modelo porque es más relevante para estudiar los efectos de las circunstancias cambiantes o de las políticas sobre el uso de la tierra y variables relacionadas.

El escenario base mostró posibles usos de la tierra atractivos. Dados los rendimientos de cosecha, el uso de insumos, y los precios relativos de insumos y productos, el palmito parece ser una actividad atractiva. Aún cuando su precio sea reducido a la mitad, el área sembrada de este cultivo se incrementaría. Este resultado soporta la tendencia actual de extender el cultivo de palmito en el área del Neguev. Es innecesario decir que la realización de un escenario así requeriría un análisis completo de los prospectos de mercadeo del palmito.

Una característica del modelo es que los aspectos de sostenibilidad están limitados a dos indicadores de sostenibilidad: agotamiento de los nutrientes del suelo y uso de biocidas. Estos se consideraron como los más relevantes en vista de las circunstancias del área. Estimar el agotamiento de los nutrientes del suelo como un flujo variable para cada LUST es exigente; aún más, comparar el agotamiento con estimados de la reserva de nutrientes en el suelo, asumiendo un período en el cual el agotamiento no afecta el tipo de uso de la tierra en cuestión - indicando así los límites de uso de los recursos - es bastante difícil. Indicar los límites al uso de los recursos, si fuera posible en conexión con la noción de la ‘tasa natural de regeneración’, sería un área importante para investigaciones interdisciplinarias futuras. Además, el efecto opuesto de un suelo menos fértil, debido al agotamiento, sobre el desempeño de un cierto tipo de uso de tierra, no es parte del modelo. Esto se podría lograr incorporando LUSTs de largo plazo, tomando en cuenta los efectos de un suelo agotado, o haciendo el modelo dinámico. Sin menospreciar estas tecnicidades, el escenario del agotamiento de los nutrientes del suelo muestra que una posible restricción sobre este agotamiento, a nivel de unidades de tierra dentro de los tipos de finca, tiene un efecto limitado sobre los ingresos de finca.
Aunque arbitrario, no es demasiado complicado construir un índice de uso de biocidas. Sin embargo, opiniones firmes sobre el impacto de los biocidas en el ambiente y sobre la capacidad asimiladora real del ambiente son muy difíciles de lograr, al menos en el presente. De nuevo, esto sería un tema de investigación importante. En el escenario de reducción de biocidas del presente estudio, se asume una reducción del uso de biocidas equivalente a la mitad del uso del escenario base, mostrando que tal reducción en el uso de biocidas es posible con pequeños efectos en los ingresos de finca. Más aún, duplicar el precio de los biocidas no afectó su uso.

**Una recomendación**

Se sugiere reemplazar la expresión planificación del uso de la tierra por el de análisis del uso de la tierra. La planificación del uso de la tierra, normalmente ejecutada al nivel subregional o mayor, tiene una tendencia a recetar el 'mejor' uso de la tierra, e implica la connotación de que se pueden tomar decisiones a estos niveles. Este casi nunca es el caso. Las decisiones de uso de la tierra generalmente se toman a nivel de finca. Claro está que estas decisiones pueden ser influenciadas por decisiones en el nivel subregional o nacional. Una toma de decisiones adecuada en estos niveles requiere de un análisis completo de las posibles decisiones de uso de la tierra a nivel de finca. Tal análisis es el objetivo principal de la planificación del uso de la tierra. Por tanto, se prefiere el análisis del uso de la tierra en vez de la planificación del uso de la tierra.
1 A NOTE ON REGIONAL ECONOMICS

Regional economics is concerned with the development of regions as territorial parts of the national economy. Relevant questions are: why are there differences within a country with regard to the production structure, incomes and employment? Why is the economy of a certain region not growing? Possible answers lie in causes like different locations, different resource endowments (natural, human and infrastructure), different histories, answers which could be conveniently summarised under the heading of comparative advantages. Generally speaking, each area tends to produce those products for which it has the greatest ratio of advantage or the least ratio of disadvantage compared to other regions (Barlowe, 1986: 219). In the context of comprehensive resource based planning or land use planning, it is important to understand that the principle of comparative advantage might 'overrule' the land use capacity or suitability assessments, both in physical as well as in economic terms, for the use of certain land units. An area might be very suitable for a certain crop, but if another area is even more suitable (because of, for example, its climate or soils, or because it is closer to the markets) for the same crop, it might have to make do with the crop for which it is somewhat less suitable. Comparative advantages is also the force behind the classical location theory of agricultural production of Von Thünen (1850). Comparative advantages should not be interpreted in a static way. Advantages can and do change, also through government action such as investment in, for example, infrastructure or education. Extensive discussions of different aspects of regional economics can be found in Richardson (1978) and Nijkamp (1986), while regional development policies in developing countries are dealt with more specifically in Richardson & Townroe (1986), and Hilhorst (1990). The text of the present appendix is an adapted version of Schipper (1987: 11-20).

Once a region has certain advantages over others, these can be strengthened by circular causation. In the context of regional development this reasoning was introduced by Myrdal (1957). Those factors which cause a region to develop more than other regions in the first place, become in turn strengthened by these factors. According to Myrdal (1957) better developed or developing regions transmit two types of effects to other regions: 'backwash effects' and 'spread effects'. The first strengthen the better developed regions at the cost of the development in the remaining regions, the second stimulate the development of the remaining regions. Both effects are composed of economic and non-economic forces.

Backwash effects. Because the centre is developing well, all kinds of enterprises (industry, transport, commerce, banks, insurance, services and cultural institutes, etc.) are attracted by the centre, which in their turn strengthen the centre. Capital is attracted because of the higher rate of return possible in the centre. Often the healthiest and the best people migrate from the periphery to the centre. Because of the concentration of enterprises and people in the centre, more and better schools and hospitals can be established. These forces prevail at the cost of the periphery. Capital invested in the centre can not be invested outside the centre. People who have migrated from the periphery cannot work for the betterment of the periphery. These processes are circular and cumulative.

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134 Better developed regions are sometimes called the 'centres', while the remaining regions are referred to as the 'periphery'.

Spread effects. Centrifugal ‘spread effects’ are the opposite of ‘backwash effects’. For example, the development in the centre leads to an increase in demand for agricultural products from the periphery which will stimulate the development there. Also, because of the increased demand for minerals from the periphery, local mining centres could be developing in the periphery, and, as a consequence, local industries for consumption goods could grow. Furthermore, the central government could stimulate the development of the periphery through the provision of schools, hospitals, infrastructure, extension, supply of inputs, etc. In this way, again via cumulative effects, the remaining regions, or centres within that region, could develop. Another possibility is that at a certain moment superfluous capital from the centre could find investment alternatives in the periphery. Alternatively the centre can become too crowded (e.g. traffic jams) causing firms to move to the (centres in the) periphery.

Myrdal is of the opinion that in general the backwash effects dominate the spread effects, especially in developing countries. This can only be changed by an active government policy, hence his advocacy of planning.

Another reason frequently mentioned for regional inequality in developing countries is their colonial past which often created a dual economy. In such a dual economy, one sector is directed at production for export, while the other is concerned with ‘subsistence’ production from which additional surplus is extracted. Between the two sectors there are insufficient links for positive influences from the export sector to the other sector. After independence this duality was often strengthened by industrialisation policies. In general, the profits and wages in the industrial/export sector are substantially higher than in the ‘subsistence’ sector. Given the diversity of this sector, it is an understatement to say that subsistence is not 100% at all. The duality argument, or in de Janvry’s (1981) terms ‘disarticulated’ (non-linked) economies, has some relevance for regional inequalities. However, sectoral inequalities often do not coincide with regional ones in a geographical way.

Another economist, Hirschman (1958) sees the same effects, but gives them different names: ‘trickle down’ instead of ‘spread effects’ and ‘polarisation’ instead of ‘backwash’. Hirschman is positive about diminishing regional economic differences, especially in the longer run. Three ideas:
1) because of the friction of distance development will first take place in certain centres (the best places in view of location), and after a time economies of scale and agglomeration will lead this development to reinforce itself;
2) although economic growth is unbalanced by its very nature, it also contains the impulse to geographical expansion; and
3) this expansion takes place via subsequent growth poles.

Changing comparative advantages points to theories of regional development and regional planning. One idea is the creation of a regional growth pole/centre to stimulate the development in a specific region. The idea of growth poles comes from Perroux (1950). He describes a growth pole as a kind of clustering of economic activities which have a higher growth rate than average and which have links with the remaining sectors. In this way the concept is not spatially linked. Boudeville (1961) interprets the concept in a regional sense and couples it to a strategy for regional development. Weaver (1981: 81) puts it in this way: "Disparities in welfare between different regions may be overcome by extending the polarised development process into depressed areas through establishment of growth centres, which link such areas to economic growth impulses generated within the broader urban system." Related concepts are growth centre and service centre. The background of these concepts is Central Place Theory, developed by Christaller (1933): on a homogeneous geographical plane with a equal distribution of resources, spatial competition arises which results in a hierarchy of centres up to 5-6 levels. This theory provides a means of ranking centres, but is mainly of descriptive and historical value and
can hardly be used as a basis for policy. Theories of growth poles have been introduced in relation to the 'key region' approach of regional planning (Schipper, 1983), but in general these theories are not very helpful in relation to regional (agricultural) development and planning, because they are not concerned with agriculture and do not have operational value. Friedmann & Weaver (1979), as cited in Riddell (1985), call them quite useless, and mention that regional planners made them a false god, to the detriment of other aspects, such as resource development.

After the Second World War the idea originated that economic development (modernisation) could be obtained by:

a) direct foreign investment (also aid);

b) development of domestic entrepreneurship and capital; and

c) development of industry and with it employment.

Related to this were ideas like the crucial role of innovations and entrepreneurs (Schumpeter, 1912) and that the government can and should intervene in the market economy in order to create full employment (crises of the 1930s/Keynes).

Originally, these ideas had no regional aspects, but the notion was soon developed and was accounted for in the theory, that national development cannot be spread over regions in a balanced way.

In order to be able to develop, the advice to 'backward' countries was:

a) to open up to foreign trade, to be stimulated by the world economy by using their comparative advantages such as labour, agriculture and minerals (in fact the export of agricultural products and minerals and the import of machines and technology);

b) to industrialise in cities (to create employment and increased demand for agricultural products); and

c) to cultivate entrepreneurship by concentrating capital in the hands of few people; growth is considered to be unequal - rather, should be unequal - in order to stimulate efficiency and savings.

Once the problem of regional inequality became clear, the case was put that 'poor' regions should develop their natural resources ('base sector') and export them (comparative advantage). By doing this the local sector could also develop through investment and market size increase. This would all be stimulated by:

a) increasing regional labour division;

b) improving of transport and communication (infrastructure); and

c) increasing trade between regions.

To summarise the above: people in regions can not supply their own needs and become richer by only using their own labour and their own resources; exchange with other regions is a *sine qua non* for the development of a region.

However, through this polarised development, the inequality of regions increased more than it decreased, therefore two alternative approaches were proposed:

1) the functional-spatial approach; and

2) the regional-territorial approach.

The *functional-spatial* approach tries to bring development to backward regions through the development of cities (centres), with certain functions in a hierarchical relation to each other, in those regions. The advantages of such a hierarchy of (service) centres are:

1) easy and efficient to a buyer, because one can combine more business on one trip;

2) reduced transportation needs;

3) decreased length of roads needed;

4) diminished costs by using common facilities;

5) ease of information exchange; and
6) development efforts for an area are concentrated into a few places with the best locations and resources, thereby increasing the chances that some of those places will develop other activities for the region spontaneously.

The emphasis in the functional-spatial approach, however, is on the integration of regions within the national entity (via a system of centres) and on specialisation in economic activities.

The regional-territorial approach uses the concept of territorial development. Territorial development is the use of the resources of an area by the population of that area for the satisfaction of their own goals: according to Weaver (1981), a regional culture, political power, and economic needs. This territorial development should be compared with functional development, meaning, as described above, the exploitation of the resources of an area only because of the role these resources play in the larger national and international economy (of course with the expectation that such resource development would also better the conditions of the population in the area).

In the regional-territorial approach conscious action of the local community is important as are the following economic concepts:

a) selective regional closure; and

b) using strategic regional advantages.

These concepts are the opposite of related concepts of 'free trade' and 'comparative advantage' according to Weaver (1981). The idea is to exploit for export only those resources in which one has a good negotiation position. In reality, there are certain sectoral developments, or certain transnational corporations will be present in a country. Nevertheless, it is important that regions give access to these only in a selective way.

For a recent review of the literature on regional and rural development and planning, see ISSAS (1986). After reviewing the main theories of regional and rural development, as well as several approaches to planning in this area, they advocate a micro-regional approach, regional rural development planning, the so-called P4-approach (van Raay, 1981 & 1982), or P3-approach in van Raay (1989). A quotation from ISSAS (1986: 153-154):

"The P4-approach aims to put into motion a rolling planning process beginning with the early identification of an initial focus based on a first reconnaissance of immediate problems, potentials, and possible long-term needs, to be followed by a gradual expansion of the sphere of inquiry and intervention with progressive attention to the long-term perspective. Specifically it recommends substituting comprehensive development plans for short-term action programmes, each covering a one to three year period in the early phases of the planned transformation of rural areas.

An action-oriented process approach is favoured which will be comprehensive in its analytical orientation and highly selective in the action it proposes at any given time. Since the ultimate aim of the regional planning can be seen as the rational and imaginative allocation of scarce resources over time and space to achieve progressively extending ends in the broad field of economic growth, social justice, environmental quality and spatial organisation, an ongoing interactive process of comprehensive analytical orientation and selective action constitute an obvious methodological choice for engaging in regional planning that intends integrated rural development.

In the outlined approach this interactive and mutually reinforcing process is structured around four main entry points, i.e. policy environment (P1), problems and potentials (P2), priority clusters (P3) and project complexes (P4). The four elements of what may be referred as the P-4 Approach constitute building stones rather than steps since basic understanding, recommendations, action-evaluation and future perspective are treated as synchronic and equally important elements of a flexible process of learning, intervention and adaptation.
What is being recommended here shares with the established planning routines an emphasis on comprehensive orientation, including attention to the long-term direction of development, but differs on the way in which such comprehensiveness is to be achieved."

Experiences (Schipper, 1983) indicate that the above mentioned theories of regional development and planning have little practical relevance for either regional agricultural planning or land use planning, although it would be easy enough to declare (and elaborate upon it) the P4/3 approach of (micro) regional rural planning another frame of reference. It could help to move land use planning out of the sphere of natural resources into the reality of society. On the other hand, land evaluation could be of use for regional planning, for example to establish the agricultural potential, which can help in determining priority areas (Schipper, 1983). The adage 'comprehensive analysis, selective action' is also attractive. However, relating land use planning too much to regional planning would also complicate the analysis severely, as well as leading to the danger that land use planning will become caught in a web of theoretical issues and practical problems, which would only hinder it. More relevant are the ideas of reducing planning efforts through a so-called ‘key-region’ approach (Schipper, 1983), comparative advantages, centres as market places for inputs and outputs, and for institutions related to agricultural development, and the creation of the proper physical and institutional infrastructure, conducive to agricultural development (Mosher, 1969).
2 A METHODOLOGICAL APPROACH TO COMPREHENSIVE RESOURCE BASED REGIONAL AGRICULTURAL PLANNING: A 'PRAGMATIC MODEL'

In regional agricultural planning, the diagnosis of the present situation is followed (in a methodological sense, the diagnosis is not necessarily completed before the planning proper starts) by an analysis of the potentials and constraints for future development. To determine those, one approach is to follow a number of steps in an iterative process. These steps are called here a 'pragmatic model for comprehensive resource based agricultural planning at the regional level'.

Without using formal mathematical programming techniques, although these are not excluded, comprehensive resource based regional agricultural planning follows a pragmatic approach to an 'optimal' (or at least 'better than at present') utilisation of resources. The procedure of plan formulation is based on gradual exclusion of development possibilities starting from a complete inventory of technical potentials and then gradually imposing constraints going from the least removable external constraints to constraints which are easier to relax, i.e. of which the resolution is in the hands of the government itself. This procedure permits the formulation of realistic objectives and the analysis of constraints provides the basis for systematic identification of projects which are designed to remove the constraints.

**Step 1** Formulation of a framework of national parameters, including objectives and constraints, guiding agricultural planning at regional level.

An analysis of the national objectives indicates the role of a given region as a part of the nation. National objectives function as conditioning factors for the reconnaissance of regional possibilities. One has to look into desired production levels for agricultural sub-sectors, desired income and employment levels, desired structural changes, and welfare and environmental aspects.

Furthermore, the following linkages between the national and intermediate level have to be known.

i) Inter-regional allocation of crops in case of competition for scarce resources;
ii) World and domestic market constraints;
iii) Prices and price structures;
iv) Taxes and subsidies and their implications for the national budget;
v) Opportunity costs of labour, capital and foreign exchange;
vi) Migration and employment opportunities outside agriculture.

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135 The first description of this 'pragmatic' model can be found in ARTJ/WAU (1981). See also Polman, Samad & Thio (1982) and Schipper (1983 & 1987). The 'pragmatic' approach will be taken up by the research programme: 'Sustainable land Use and Food Production in the Tropics' ('Duurzaam Landgebruik en Voedselproductie in de Tropen'). This is a joint research programme of several departments of the Wageningen Agricultural University and research institutes of the Netherlands Ministry of Agriculture, Fishery and Nature Management (DLV, 1990). The present research is connected methodologically as well as institutionally to this 'DLV' programme.

For related approaches to regional (agricultural) planning, see: van Dusseldorp & van Staveren (1980) and Luning (1981).
Step 2 Inventory of land and water resources and estimation of technical possibilities for land use types (crops, livestock and other).

The inventory of land resources derives from a land suitability map, which indicates the suitability of different soil types for different land use types. Both existing land use types and land use types that could possibly be applied in the prevailing ecological conditions have to be taken into account. Also soils which have to be excluded from regular cultivation because of a heavy risk of erosion must be identified.

Comparison of the land suitability map with the present land use indicates the potential changes in land use. Agronomic expertise should indicate the expected potential yields of different land use types on different soil types. Comparison with present yields indicates the technically feasible production increase. Inventory of water resources consists of the availability of surface water and ground water. The potential area for irrigation can be derived from this. Different types of irrigation have to be distinguished (gravity irrigation, lift irrigation, wells, tubewells, etc.). The possibilities for irrigated versus rainfed cultivation have to be included in the estimation of potential yields.

A helpful tool of analysis is the breakdown of the region under study into agro-ecological zones which embody the natural constraints on crop development.

Step 3 Imposing supra-regional constraints on land use type development.

World and domestic market constraints may reduce the technical potential for the land use types (linkage ii). Also important are the price and price structure (linkage iii), and the relations between supply, demand and price development. Study of the comparative advantages of land use types in different regions may further reduce the potential for production increase in the region concerned (linkage i).

Step 4 Economic feasibility of land use types.

Analysis of inputs and outputs of land use types determines the present and the potential income and employment on a per hectare basis. Input-output analysis should be specified for different levels of technology used or potentially used by farmers. Input-output analysis should be based both on market prices and on economic prices. They reflect the economic feasibility from the private point of view and the social point of view respectively (linkage iii).

In the former case taxes and subsidies are considered to be costs or benefits in production, in the latter case they are seen as transfers of income accruing to other social groups (linkage iv).

Step 5 Imposing constraints at farm level.

Land use types may be economically feasible as such, but they do not necessarily fit into the farming system. The following constraints may play a role
- labour shortages in peak periods;
- farm size (some crops require large scale cultivation);
- competition for land in the case of rotational cropping;
- farmers' motivations in the adoption of new technologies and crops (social prestige, risk avoiding behaviour, preference for leisure, land tenure relationships, preference for non-agricultural activities in part-time farming).

Step 6 Identification and choosing of options, scenarios.

Scenarios indicate and describe possible developments with regard to certain parameters and their influence on key indicators like objectives (e.g. incomes, employment) and land use. Scenarios can provide decision makers with an insight into the consequences of certain major decisions.
A 'pragmatic' model

Examples of major decisions are two types of options which may be implemented: structural and non-structural. Structural options refer to changes in the distribution of and the accessibility to factors of production, land in particular, and to irreversible decisions which fix the land use definitely or for a very long time (for example the planting of tree crops, the construction of irrigation schemes, the neglect of erosion for social reasons). Non-structural options refer to changes in the cropping pattern within the existing landownership and land tenure situation and to intensification of production within the existing land use pattern. The word 'non-structural' does not imply that such changes are insignificant.

Within the options for either structural or non-structural development, one has to select those technically, economically and socially feasible activities which most contribute to the declared socio-economic objectives. One has to weight these objectives if there is a trade-off between production, income and employment. The distribution of the same objectives over social groups (farmers and landless people) and over (sub-)regions is a further criterion for selection of agricultural activities.

**Step 7** Identification of projects and programmes in a long-term perspective.
On the basis of the agricultural activities selected one proceeds to the identification of projects and programmes which are to bridge the gap between the present and potential situations. The projects (and programmes) have to be designed to remove the constraints detected in the preceding steps at regional and at farm level. In this way a direct relation is established between actions, constraints and objectives. Projects will also be localised fairly precisely on the land suitability map and the beneficiaries will be defined in terms of types of farms. Project (and programme) identification should also comprise (as far as possible benefits do not escape quantification) a cost benefit analysis (linkage v) including calculation of project outputs, effects and impacts.

**Step 8** Reconnaissance of the future role of agriculture within the region.
The calculation of project impacts in terms of production, employment and income plus an assessment of autonomous development indicate the future capacity of agriculture in the region to employ people gainfully. Standard norms for income and employment per person or household have to be applied to determine how many people or households can be gainfully employed in agriculture in the expected future situation. This number is to be compared with the expected population and the expected employment and income opportunities outside agriculture both in the region and outside the region.

Emigration movements may relax population pressure. In the case of under-population one should assess immigration tendencies and provide for settlement schemes (linkage vi). The assessment of this capacity of both the agriculture in the region and the non-agricultural sectors in and outside the region permits a prediction on whether the socio-economic situation is likely to improve or to deteriorate. On the basis of such insights one may revise the options and repeat the plan formulation process (iteration).

**Step 9** The budget and the implementation capacity as a basis for final project selection.
The projects so far formulated in a long-term perspective have to be translated into a medium-term plan and annual action plans. In other words one has to phase the projects out. This again leads to policy options regarding the acceleration or deceleration of development in certain sectors or regions. Choices must be made as the budget will usually be insufficient to do everything at the same time. Moreover, financial commitments do not normally stretch over more than a few years. Another problem is that implementation capacity may not be sufficient, or adequately balanced over sectors and regions, to carry out the programme. Implementation capacity may be bought for money to a certain extent, but it is also a matter of (re-)organisation.
Training of staff takes time. Plan formulation should also comprise the action necessary to strengthen implementation capacity. The phasing of the plan on the other hand depends on the pace at which implementation capacity will be built up.
After an exploratory survey in May/June, 1986 (van Sluys et al., 1989), the Atlantic Zone Programme organised a baseline survey in February 1987 among 149 farms in three sub-areas of the Northern part of the Atlantic Zone: Neguev, Río Jiménez and Cocori. The collected data are reproduced in Brink & Waaijenberg (1990). The major results for the Neguev can be found in Waaijenberg (1990). Schipper (1993) presents a comparison between the three areas.

Apart from the methodology, some indications are given for the following subjects: household composition, labour-equivalents, off-farm work, capital goods, input use, land use and major crops, and livestock.

The baseline survey was intended to obtain insight into different farming systems and the land use and other activities of the farm households. In the Neguev 53 farms were selected at random out of a list of the Instituto de Desarrollo Agropecuario (IDA) of the 310 (registered) farms in the settlement. Farms were visited once. Sub-samples were visited one more time to obtain more details about specific crops or livestock activities.

In 1987, an average of 5.3 persons were living on a farm, spread over 1.21 households. Of the 5.3 persons, 2.3 were in the age group 0-14 years, 0.7 in the age group 15-20, 2.2 in the age group 21-60, and 0.1 in the group above 60 years (Waaijenberg, 1990: 34). In comparison to the neighbouring district Río Jiménez, there were many children below 15 years and few elderly people (Schipper, 1993: 23). This is related to the average age of the head of the household (37 years), which is young. On average, the amount of schooling received by these heads of household is more than in the neighbouring area. Such characteristics are typical for a recent settlement area. Potentially, taking together the age categories of 15-20 and 21-60 years, 2.9 persons per farm (1.7 male, 1.2 female) were available for work. It was found that on average 0.7 person, nearly all male, was working off-farm. Few indications were obtained about how many days per year off-farm work was done. However, with regard to the head of the households, 2% did not work their own farm, another 2% spent less than a quarter of their time on their own farm, yet another 2% spent between a quarter and half of their time to on-farm work, 15% of the farmers dedicated between half and three quarters of their time to the farm, 13% between three quarters and full time, while the remainder of the farmers (66%) only worked on their own farm.

The most common capital goods were knapsack sprayers for applying biocides, especially herbicides. These were used on 93% of the farms, however, only 60% of the farmers possessed one or more knapsack sprayers. The next important capital good was a chainsaw, indicating a need and opportunity for cutting trees. These were used on 43% of the farms and owned by 26%. About 30% of the farms had a vehicle, mostly used for transporting products or inputs. Tractors were used on 26% of the farms, mostly for soil preparation, but nobody owned a tractor. The most commonly used equipment is, of course, the machete, as farming, or indeed living, without one is virtually impossible. Every farmer had a sufficient number of machetes. As they wear out quickly under intensive use, barely lasting for a year, machetes can hardly be classified as a capital good.

The baseline survey did not reveal the use of current inputs with much precision. At farm level, excluding the hire of machinery, it can be guestimated that fertilisers (39%) and herbicides (34%) are most important in the costs of inputs. About 7% was spent on purchased seed, while on average 11% was needed for veterinary medicines.
As mentioned in Section 6.1, land use in 1987 can be found in Table 6.1. On the basis of total land use, the average land use per farm can be calculated. It should be noted that land use is very variable. For example, on average, 47 farms (out of 53) in the Neguev planted annual crops on 3.4 ha, 36 farms cultivated perennials on 1.6 ha per farm, while 48 farms had 5.8 ha with a form of pasture (Waaijenberg, 1990: 41). However, the ranges between the minimum and maximum values for these three variables are 0.2-12.5 ha, 0.2-5.0 ha and 1.0-13.5 ha, respectively.

In Table A.1 one can observe the most important crops, i.e. those crops of which at least 20% of the farmers indicate that the crop belongs to the four most important crops on the farm. Maize was considered the most important crop, followed by cassava, beans and plantain, pineapple, cacao, coconuts and rice. The sequence of importance does not coincide with the average area on the farms that did cultivate a crop. Note again the wide range of the areas.

As can be inferred from the large area with pasture (Table 6.1), livestock activities are important in the Neguev. In 1987, 74% of the interviewed farms had cattle (Schipper, 1993: 13). On those farms, the average herd size was 13.7 head. The total number of cattle in the Neguev was estimated to be about 3100 head. Expressed in animal units, on average 1.5 animal units are kept per ha, which is more than the average for the whole Atlantic Zone. Almost all farms which kept cattle did so for producing calves and milk. Of those farms, 82% had an average herd size of 9.2 animal units, while on 18% of the farms the herd size was 31.1 animal units. On only one farm out of 39 farms, were cattle held for fattening; the herd size was 30 animal units.


137 In Costa Rica an animal unit is calculated as 1/3 * (animals younger than one year) + 2/3 * (animals between 1 and 2 years) + (animals two or more years).

Table A.1 Importance and area of some crops in the Neguev, Costa Rica, 1987

<table>
<thead>
<tr>
<th>Rank</th>
<th>Crop</th>
<th>Number of farms(^1)</th>
<th>Percentage of farms(^2)</th>
<th>Area per farm(^3) (ha)</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maize</td>
<td>29</td>
<td>55</td>
<td>3.9</td>
<td>0.25-12.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cassava</td>
<td>28</td>
<td>53</td>
<td>0.9</td>
<td>0.25- 3.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Beans</td>
<td>26</td>
<td>49</td>
<td>0.7</td>
<td>0.12- 5.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Plantain</td>
<td>23</td>
<td>43</td>
<td>1.3</td>
<td>0.25- 3.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Pineapple</td>
<td>15</td>
<td>28</td>
<td>0.5</td>
<td>0.25- 1.0</td>
<td></td>
</tr>
<tr>
<td>6/7</td>
<td>Cacao</td>
<td>13</td>
<td>25</td>
<td>1.9</td>
<td>0.50- 3.0</td>
<td></td>
</tr>
<tr>
<td>6/7</td>
<td>Coconut</td>
<td>13</td>
<td>25</td>
<td>not known</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Rice</td>
<td>11</td>
<td>21</td>
<td>1.4</td>
<td>0.25- 6.0</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Number of farms on which a crop is considered to belong to the four most important crops of that farm.
\(^2\) Percentage of farms (out of 53 farms) on which a crop is considered to belong to the four most important crops of that farm.
\(^3\) Area of crop on the farm on which the crop is considered to belong to the four most important crops of that farm.

Schipper (1993: 24-32) used the 1987 survey results to elaborate a farm classification, based on location, farm size and land use. The location was based on the sub-area either Neguev, Río Jiménez or Cocori. In order to obtain an equal number of farms in each group, farm size groups were made on the basis of the median size, in the Neguev 11.9 ha. For land use two criteria were used, percentage of land under annual and perennial crops, including fallow land, and the percentage of land under pasture. Again, for both criteria the median percentage was used as the cutting edge. In the Neguev, in the case of small farms, for crops this is 30%, for pasture 53%. However, in the case of large farms, for crops the median is 26%, for pasture 35%. In total, eight farm classes were thus distinguished. The results are summarised in Table A.2. The main purpose of this table is to discover the major differences in land use between larger and smaller farm in 1987. For example, small farms had relatively more land in use for crops and pasture than large farms. Furthermore, most farms concentrated either on crops (33-39%) or livestock (33-35%), a minority (12-15%) had a relatively small area only of both crops and pasture, while another minority (15-19%) had a relatively large area of both crops and pasture. This farm classification is not used for the grouping of farms for the linear programming model (Section 6.4), as the objective of the linear programming model is to determine the land use for each group, including the choice between crops and pasture. In that case classification on the basis of present land use does not make sense.
Table A.2 Farm classification in the Neguev, Costa Rica, based on 1987 survey: percentage and number of farms in each class

<table>
<thead>
<tr>
<th></th>
<th>small farms (less than 11.9 ha): 26 cases</th>
<th>large farms (more than 11.9 ha): 27 cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>part of farm area with crops</td>
<td>part of farm area with crops</td>
</tr>
<tr>
<td></td>
<td>less than 30%</td>
<td>less than 26%</td>
</tr>
<tr>
<td></td>
<td>more than 30%</td>
<td>more than 26%</td>
</tr>
<tr>
<td>part of farm area</td>
<td>less than 53%</td>
<td>less than 35%</td>
</tr>
<tr>
<td>with pasture</td>
<td>12% (n=3)</td>
<td>15% (n=4)</td>
</tr>
<tr>
<td></td>
<td>more than 53%</td>
<td>35% (n=9)</td>
</tr>
<tr>
<td></td>
<td>39% (n=10)</td>
<td>33% (n=9)</td>
</tr>
<tr>
<td></td>
<td>15% (n=4)</td>
<td>33% (n=9)</td>
</tr>
<tr>
<td></td>
<td>19% (n=5)</td>
<td>19% (n=5)</td>
</tr>
</tbody>
</table>

Source: Schipper (1993: 26).
During 1991 and 1992 a farm survey was held in Neguev to establish relationships between land units, land use types, input and factor use, outputs, and economic returns. These points are in line with the topics for land use oriented surveys outlined in Section 4.5.2.1. The results are mainly used to construct 'present' LUSTs, land use systems based on actual technologies currently practised on real farms (Section 7.3; Jansen & Schipper, 1995). As it was necessary to obtain detailed data of good quality, it was felt that a multi-visit survey, visiting the farms every week for at least a year, was appropriate. Given the limited means of the programme only a small number of farms could be studied. Stratified, a-select sampling did not prove to be a success: too many farms on the list of the sampled farms no longer existed, or were not 'at home' after trying three times, or did not like to cooperate, or stopped cooperation after a short period (Finnema, 1991: 2-4; van den Berg & Droog, 1992: 3-4). Therefore, the 13 farms finally included in the survey\textsuperscript{139} can better be interpreted as 13 case studies. No 'average' results can be presented, nor, obviously, statistical measures for variability. The results in each case differ from those in the other cases. Each farm finds particular 'solutions' for their particular 'problems'; in doing so some have more success than others, in particular with regard to the overall income. Results of the survey\textsuperscript{140} for the individual farms, as well as for the most relevant land use systems, can be found in Finnema (1991), van den Berg & Droog (1992) and Akkermans (1994).

Nonetheless, below, five of the 13 farms are presented as being 'representative' for the five farm types as distinguished in Section 6.4. 'Excursions' are made to the remaining eight farms. Declaring a specific farm representative for a group of farms is tricky; it is more akin to a rough and ready approximation. And certainly, it should be seen as a personal interpretation by the researcher.

In Section 6.4, these five farm types are drawn up on the basis of farm size and the relative area of each of the three main soil types (Table 6.2). Here Table A.3 is presented, showing the assignment of each of the 13 survey farms to a farm type. Furthermore, the land resources of each farm are displayed plus the farm gross margin per year as obtained in 1991 and/or 1992.

\textsuperscript{139} An additional seven farms were studied in the same way in the neighbouring Río Jiménez district during 1992 (Valverde, 1994), while in 1993 ten farms in Cocori were visited once every fortnight (Valverde, 1995).

\textsuperscript{140} The data of the survey are stored in a Dbase IV data base file. Preliminary analysis for each activity (per ha) of each farm was done with the help of tailor-made software, PEPE6, developed by José Arze and Leopoldo Gómez of CATIE. The software creates tables per activity showing quantities of inputs and outputs, as well as similar tables per activity showing labour use, specified as household labour or hired labour for each operation. Furthermore, the software presents summary tables of benefits and costs per activity and tables showing the cash flow per activity. Finally, for each farm in the survey a table is created that permits a whole farm economic analysis.
Table A.3  Land resources and farm gross margin of 13 farms surveyed in the Neguev, 1991-1992, plus assignment of each farm to a farm type

<table>
<thead>
<tr>
<th>Farm identification¹</th>
<th>Farm type²</th>
<th>Area³ (ha)</th>
<th>Area⁴ (ha)</th>
<th>Area with soil type⁴ (%)</th>
<th>Farm gross margin (₪ year⁻¹)</th>
</tr>
</thead>
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Individual farms are identified by letters to avoid confusion with the number of a farm type. The correspondence with the farm numbering as in the reports of Akkermans (1994), van den Berg & Droog (1992) and Finnema (1991), abbreviated as A, B&D and F, respectively, is as follows:

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¹ Individual farms are identified by letters to avoid confusion with the number of a farm type. The correspondence with the farm numbering as in the reports of Akkermans (1994), van den Berg & Droog (1992) and Finnema (1991), abbreviated as A, B&D and F, respectively, is as follows:

² See Section 6.4, Table 6.2

³ Based on van den Berg & Droog (1992)

⁴ As measured from a digitalised map combining soils and IDA farms (parcelas)

As one can observe in Table A.3, resources per farm are quite different, as are the farm gross margins. This will be discussed in detail per farm type. On average, farm type 1 is a small farm (15.7 ha) with 60% fertile poorly-drained soils (SFP), 12% fertile
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well-drained soils (SFW) and 28% unfertile well-drained soils (SUW)(Table 6.2). Farm G is the only farm of the 13 survey farms that could be considered for this group. The farm has 9.9 ha, of which 5.8 ha is SFP and 3.9 ha SUW. Only 2.0 ha of the SFP soil is used for pasture, the rest is scrub and secondary forest. However, the farmer did not possess cattle. Crops were planted on the SUW soils: 1.0 ha palm heart, nearly one ha with eddoe (chamol & nampi), 0.6 ha with greater yam (ñame), 0.2 ha with pineapple, 0.1 ha with beans (frijol) and 0.1 ha with coconut. The gross margin from crops is about $200,000 per year, of which palm heart is the most important (45%), followed by eddoe (35%) and pineapple (16%). The total family income is supplemented by working off-farm. However, this only generates 2% of this income. On-farm household labour income per hour worked is $211, well above the hourly wage for day labour ($100). Nevertheless, the yearly income is low by Costa Rican standards. Household labour was supplemented by hired labour (490 hours). In 1991, the family consisted of man (age 47), wife (age 42) and two adult sons (ages 21 and 20), of which the eldest had fixed employment in a cardboard factory. His income is not included in the above calculations.

On average, farm type 2 are large farms (32.1 ha) with 12% SFP soils, 10% SFW soils and 78% SUW soils (Table 6.2). Of the surveyed farms, only farm L can be reckoned to belong to this group. The age of the farmer is 62, while his wife is 60. They have 11 children, of whom none live on the farm. He possesses a farm of 12.4 ha, but rents two additional pieces of land (parcelas in the local terminology) of 17 ha each. For one of these parcelas he pays $5,400 per month, for the other he renders services in the form of felling trees. All the soils belong to the SUW type. His major activity is livestock on 45.6 ha with pasture. He also planted 0.5 ha with pineapple. This was not a success, only yielding 700 pineapples per ha. On the pasture area he fattens about 30 animals per year, earning him a gross margin of $490,000 per year, for which he has to work 580 hours. Per hour worked, this is $850. Per ha of pastures, it gives a return of $10,800. Of course, where the land is rented, rent has to be deducted. This can be estimated to be about $3,800 (12 * $5,400 / 17) per year. In addition to his farm, he owns a workshop in a nearby village in which he saws trees into planks. Working about 600 hours, he earns $650,000 per year with this activity. Per hour worked, this is $1,080. Occasionally, day labour is hired (150 hours per year).

Farm type 3 are on average small farms (13.5 ha) with 7% SFP soils, 52% SFW soils and 41% SUW soils (Table 6.2). Out of the surveyed farms, two might be representative, although both have too large a percentage of SFP soils. Farm E will be presented here. It has 17.2 ha of which 6.9 ha is SFP, 6.5 ha SFW and 3.8 ha SUW soils. The farmer uses only his SFW soils, mainly for crops, which he (partially) interplants. Within these soils six plots can be distinguished. On plot 1 (0.5 ha), he planted his first maize crop, part of his first pumpkin crop and later the second pumpkin crop. On plot 2 (0.7 ha), after clearing cacao which was infected by the monilia fungus, he planted his second pumpkin crop. In-between the pumpkin, a month before harvest, young papaya was planted. On plot 3 (0.9 ha), part of the first pumpkin crop was planted, followed by the second maize crop mixed with chili. Plot 4 (0.5 ha) was planted with the second maize crop together with the second cassava crop. Plot 5 (0.7 ha) was planted with the first cassava crop, followed by the third pumpkin crop. Finally, plot 6

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141 The physical yields per ha per year for these crops are the following. Palm heart: 3,690 candelas (harvested palm hearts) (with 3,800 palms per ha), eddoe: 4,150 kg, greater yam: 1,660 kg, pineapple: 14,880 kg & 4,080 pineapples (probably of classes II and III; 1.94 and 1.43 kg per pineapple, respectively) and coconut: 16,500 nuts. No yield for beans was reported.
Appendix 4

(2.9 ha) had some secondary forest, cacao and pasture (1.0 ha)142. If we look at his farm gross margin $188,000 in 1991, 63% was earned by pumpkin, 36% by maize and 10% by cassava143. To obtain this gross margin, the farm household worked 1,330 hours, earning a return of $140 per hour worked. The farm gross margin is supplemented by some off-farm income ($8,400). This appears to be too low. However, the farmer and his wife (both about 40 years old) live with two sons, both about 20 years, of which the eldest is married. This couple has a small baby. The eldest son is not working on the farm, but has a job elsewhere. The youngest son does help his father, but he is also working off-farm for part of the year. Thus, both sons have outside income, part of which will be used for supporting their parents. Day labour is hired for some 350 hours per year.

Farm B is the other farm in this group. The farmer is 66 years old, while his wife is 58. Land use resembles that of farm E. The farm is 19.9 ha, consisting of 5.4 ha SFP, 8.7 ha SFW and 5.8 ha SUW. An important land use is 'summer' maize (3.2 ha, January to May), intercropped in part with cassava (2.1 ha). The farmer also plants 'winter' maize (1.2 ha, June to December). Another important crop is pumpkin, also planted twice, 1.5 and 1.0 ha, respectively144. Later in the year one hectare was planted with chili. Furthermore, there are small areas with greater yam, eddoe, beans and plantain. Lastly, the farm had 1.3 ha of cacao, but this will be cleared due to monilia infestation. In 1991, the farm gross margin of $269,000 came mainly from maize (39%), pumpkin (34%) and cassava (26%). The family worked 1,250 hours on-farm, earning a return of $215 per hour worked. The farmer and his wife, as well as their daughter of 17, do not work off-farm, but as they have two grown-up sons who work for two periods of three months per year on banana plantations, the family income is supported by off-farm income. Day labour is hired for 670 hours per year.

On average, farm type 4 consists of farms of 14.1 ha with 3% SFP soils, 91% SFW soils and 6% SUW soils (Table 6.2). With regard to soil quality, this type of farms is best equipped. An example is farm D. This farm has 16.0 ha, with 4.3 ha SFP soils and 11.7 ha SFW soils. Land use is fairly complicated as 15 plots can be distinguished during the two years (1991 & 1992) of interviewing. Crops are normally planted in plots on SFW soils, however, sometimes in plots partly on SFP soils. Next to 6.7 ha of pasture, the basic feature is a gradual transition from cacao and annual crops (maize and cassava) to plantain and palm heart. While plantain and palm heart are young, they are (in part) interplanted with cassava and pumpkin (0.6 ha), with pumpkin alone (0.5 ha) or with

142 Under conditions of intercropping, it is difficult to estimate yields. However, being bold, the following can be stated. His first maize crop failed due to heavy rains and inundation. His second maize crop yielded 760 kg (19 bags of about 40 kg each), plus 19,000 cobs per ha. His first cassava crop yielded 3,300 kg per ha, while the second one was due to harvest after the end of the interviews. Chili failed altogether, due to heavy rains and inundations. The first pumpkin crop yielded 7,600 kg per ha, while the second yielded 3,100 kg per ha. The third pumpkin crop was only just planted by the end of the interviews. The same applies for papaya.

143 These percentages add up to 109% of the farm gross margin. However, this farm gross margin is net of the losses occurred with the failed crops, which is about 10% of the mentioned gross margin.

144 The 'summer' maize yielded 3,760 kg (94 bags of about 40 kg per bag) per ha plus 280 fresh cobs per ha. The first cassava crop had a yield of 6,400 kg per ha, while the production of the first pumpkin crop was 6,900 kg per ha.
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Plantain is also planted alone (0.4 ha) or in combination with palm heart (0.9 ha). The latter is not a success as the plantain provides too much shade for the palm heart. As well as the areas with plantain and/or palm heart, maize is still planted alone (0.3 ha) or interplanted with cassava (1.1 ha). The farm gross margin was $476,000 per year. Crops provided 71% of this gross margin, livestock the remainder. The most important crops with regard to the farm gross margin were palm heart (19%), maize (23%), plantain (16%), pumpkin (6%) and cassava (6%). When the interviews started the farmer (age 30) was still a bachelor. In addition to his own labour (1,450 hours per year), he hired 1,980 hours of day labour year. The household labour gave a return of $330 per hour worked. The farmer worked about 40 hours per year off-farm.

The other two surveyed farms that could be included in farm type 4 are following quite different routes. Farm A consists of 14.8 ha owned by the farmer plus 6.0 ha rented land, all SFW soils. The farmer (age 47) mainly depends on off-farm work. He works for the municipality, which gives him a regular job and steady income. He also works his farm, but this gives a low return. The most important crops are cassava (6 ha), pumpkin (2.1 and 0.5 ha) and maize (2 ha). However, the cassava yield was only 1,100 kg per ha. The results for pumpkin were mixed, 2,400 kg and 10,000 kg per ha, respectively. Maize yielded 2,400 kg (60 bags of about 40 kg each) per ha. These three crops provided 34%, 63% and 54% respectively of gross margin, net of losses, with regard to crops ($92,000 per year). Net of losses as other crops failed: maize, chili and plantain. Livestock is supposed to contribute more to the farm gross margin, and did so considerably from mid 1990 to mid 1991 ($460,000), but not in the remainder of 1991, while in 1992 no sales were reported. This resulted in a negative livestock gross margin of $17,000 in 1992. As the household did some 1,250 hours on-farm work, the return to this labour is only $60 per hour worked. Off-farm income is a considerable part of the household income, not only because of the job of the owner, but also because of two adult sons living on the farm.

The third farm in this group is farm F, with 10.2 ha, of which 7.3 ha are SFW soils and the remaining 2.9 ha SUW soils. The farmer earns most of his income from crops and livestock. Remarkably, his SFW soils are not used for crops as the particular soil, locally named Destierro, although fertile and well-drained, is too frequently inundated for crop cultivation. Therefore, this part of the farm is used for livestock. The SUW soils are used for crops, in particular maize (0.5 ha), beans (three times 0.5 ha), chili (two times, 1.0 and 0.5 ha, respectively), plantain (0.3 ha), pineapple (0.5 ha), different fruit trees (0.5 ha), coconut (0.5 ha) and palm heart (0.5 ha). The crops contributed 58% to the farm gross margin of $756,000 per year. Pineapple was by far the most important crop in this respect. The remainder of the farm gross margin came from livestock. The farmer

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145 Without separating the interplanted crops, the following yields per ha are guestimated. The first maize crop: 4,080 kg (102 bags of about 40 kg per bag), the second maize crop: 1,200 kg (30 bags) and 4,300 fresh cobs and the third maize crop: 5,720 kg (143 bags) and 150 fresh cobs. The first cassava crop: 4,900 kg, the second one: 8,000 kg. Pumpkin yielded 5,000 kg. Plantain, per year (1992): 540 bunches (each bunch has between 30-35 plantains weighing, according to Central Market standards, each 425 grams). Finally, in 1992 when all palm heart became productive, it yielded 4,800 candelas.

146 As far as is known, yield per ha are the following. Maize: 4,800 kg (120 bags of about 40 kg), the first bean crop: 782 kg, the second bean crop: 390 kg, and pineapple: 50,000 pineapples, probably of class II and III. Both coconut and palm heart were too young for a yield.
Appendix 4

(age 48) and his wife (40 years) have three sons (ages 18, 17 and 7) and one daughter (age 10). The eldest son works in a nearby ornamental crops plantation. The middle son helps with farm work. In total 1,065 hours per year were spent on-farm work, earning a return of £710 per hour worked. The farmer hired 70 hours of day labour. In total 470 hours were worked off-farm. The farmer is highly motivated to cultivate his land very carefully in order to maintain this resource. For example, on a steep part of his pineapple plantation, he cultivates the pineapple between lemon grass (Zacate de limón), in order to reduce erosion.

Farm type 5 consists of farms of, on average, 13.8 ha with 6% SFP soils, 6% SFW soils and 88% SUW soils (Table 6.2). Farm J is a (successful) example of such a farm. The farm of 10.8 ha, plus 2.0 ha rented-in, consists completely of SUW soils. The farmer specialises in palm heart, for which he created a plantation of 4.5 ha in a number of years. However, as well as palm heart, during the two years of interviews, he cultivated maize (2.0 ha), cassava (2.0 ha), greater yam (1.0 ha), beans three times (0.8, 0.7 and 0.7 ha, respectively), chili three times (0.8, 0.5 and 0.8 ha, respectively), pineapple twice (1.0 ha each), and passion fruit (1.0 ha)\textsuperscript{147}. Furthermore, he has 4.8 ha of pasture on which a number of cows are kept, mainly for domestic milk consumption by his large family. The yearly farm gross margin was £967,000, for which the main source was palm heart (91%). Most of the palm heart is sold as palm hearts (candelas) to a factory, but a part is cut into small pieces and sold in small bags on a local market. The farm gross margin is supplemented with off-farm work, earning an additional £65,000 per year. The farm household is large, the farmer and his wife, both in their forties, have eight children, four daughters and four sons. One of the daughters is married. One of the sons works full-time on the farm, another one half-time. All other family members, except for the smallest, help as well. Per year, the household members work 3,260 hours on-farm, giving a return per hour of £300. Additionally, the farmer hires 740 hours of day labour. The farmer works 440 hours per year off-farm.

Not all farms of type 5 are equally successful. Earning a reasonable farm gross margin is not directly related to land use choices. Of the six surveyed farms classified as type 5, three farms emphasised palm heart cultivation, all with 100% SUW soils. However, during 1991 and/or 1992, only two had good to reasonable farm gross margins of £967,000 (farm J, 91% came from palm heart, see above) and £313,000 (farm I, 61% from palm heart), respectively. The third farm, farm K, had a rather low farm gross margin (£63,000), caused by investing in palm heart planting (3.0 ha), which in 1992 still had a low yield. Presumably, from 1993 onwards the yield of palm heart will be normal. A fourth farm in the type 5 group, farm C, has not started to cultivate palm heart, but sticks to annual crops like maize and cassava. The farmer can do so because 3.2 ha (19% of his farm of 16.2 ha, plus 0.7 ha rented-in) is SFW soils. In effect, he is not using the remaining soils (SUW) for crops, but only for a small pasture area of 2.5 ha. Earlier, he had 1.5 ha of cacao on these soils, however, this no longer yields, due to the monilia fungus. It will be no surprise that his farm gross margin is low, £25,000. In 1991, this was supplemented by £11,800 off-farm income. Such an income is far to low to exist upon, so he will have had other income sources, such as remittances from children. The fifth and six farm belonging to type 5, farms H and M, have 11.8 and 9.5

\textsuperscript{147} Yields per ha are the following. Maize: 240 kg (6 bags of about 40 kg), cassava: 9,700 kg, first bean crop: 60 kg, second bean crop: 120 kg, first chili crop: 110 kg, second chili crop: 7,600 kg plus 22 bags, first pineapple crop: per year, 1,600 kg plus 1,300 class II pineapples, passion fruit: 30 kg plus 740 fruits, and palm heart: per year, 5,000 candelas plus 870 small bags of palm heart slices, each bag containing 1.5 candela.
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ha, respectively. The farms opt for both crops and livestock. Their soil resources are similar. Farm H has 2.6 ha SFP, 1.3 ha SFW and 8.0 ha SUW soils. The main crops are cassava (1.7 ha) and pineapple (two crops of 0.8 and 1.0 ha, respectively). The farm gross margin was £136,000 in 1991. Cassava contributed 57%, and pineapple 42%. However, the first pineapple crop had a gross margin of £163,000, and the second had a loss of £105,000. Although the farm had 7.6 ha with pastures, no income was generated. No off-farm income was reported. Farm M, of 9.5 ha, consists of 1.6 ha SFP soils and 7.9 ha SUW soils. The only crop is 3.0 ha with palm heart on SUW soils, the remainder of the farm is pasture (6.5 ha). His annual farm gross margin of £368,000 consists for 37% of palm heart revenues, the rest comes from livestock. The farm gross margin is supplemented with off-farm earnings of about £129,000 per year.
5 AN ALTERNATIVE FORMULATION OF THE LABOUR MARKET

The model REALM as formulated at present is rather insensitive to changes in wages, because labour is both a cost as well as a benefit. Furthermore, no labour can be attracted from outside the Neguev. However, the (binding) labour constraints have an important impact on land use decisions. Therefore, including in the model a possibility to hire labour from outside the area might change the resulting land use. Another mentioned problem (Section 7.3) is that although the model does contain farm types, the objective function, being the sum of the economic surpluses of the individual farm types, is a collective surplus. Below, an attempt is made to examine the consequences of the model's peculiarities in these respects.

REALM is an optimisation model regarding land use. Elsewhere (Section 5.1), it has been stated that decisions regarding land use are taken at the farm level, but that these decisions can be influenced by policy measures decided upon at the (sub-)regional level. Therefore, it was deemed important to simulate the situation at the farm level regarding objectives, options and constraints in order to be able to evaluate possible policies. Thus the interpretation of the objective function and the constraints regarding the behaviour of the farmers are important.

Land and labour constraints are set at the farm level, although labour is also constrained at the sub-regional level (equation of aggregated hired labour with aggregated off-farm work on other farms within the Neguev; limited aggregated plantation work). This way of formulating constraints is thought to be a reasonable approximation of reality. The mentioned equation constraint of inter-farm labour within the sub-region is an equilibrium condition of the model {equation (6.13)}. Such conditions or 'system constraints', are also called 'closures' (Robinson, 1989), in this case at the sub-regional level.

As the objection function is a collective surplus, it might be beneficial for the model to have a higher surplus of one farm type at the cost of that of another. An example of this occurred in the present land use scenario (Section 7.3). Such a set-up could be interpreted as representing a situation in which a planner at the level of the Neguev dictates land use and allocates labour among the farms. In doing so, the planner tries to maximise the total economic surplus in the Neguev, but might find it necessary to sacrifice economic surplus of one or more farm types in order to increase the surplus of other farm types by a larger amount. Thus, the model does not represent a situation in which each representative farm is maximising its own surplus and in which all farms compete for the existing pool of labour in the Neguev (Norton, 1995b: 10). In order to circumvent this difficulty, Norton suggests four ways to modify the model so that the farm types correspond better to the behaviour of decentralised decision makers.

Regarding the four ways, Norton (1995b: 10-11) states the following:

"a) Solve each representative farm model separately, rather than tying them together in a single zonal or regional model. In this case, the assumption of limited local labor would have to be dropped, and it would have to be assumed that labor is available in infinitely elastic supply at the going rate for interfarm work, i.e. for labor brought in from other farms in the region. In the aggregate, this assumption about the labor market would not be realistic.

b) Solve the farm models together but allow unlimited supplies of labor at the rate for interfarm work, i.e. for labor from any class of farm in the region working on lands of another class. Again, this assumption would not accord with the realities of the labor market in the region."
c) For the farm models grouped together, model the labour supply market as described in Hazell and Norton (1986, p.p. 210-205).

d) Solve the group of representative farm models together, with the existing objective function, under an iterative procedure that, for the month in which the solution's total labor use exceeds the amount available locally, successively increases the wage for local farm labor in the objective function in the succeeding rounds of the solution process. This procedure continues until the wage in those months is high enough that labor use no longer exceeds the availability. [...] At convergence, the solution of this procedure will represent a market-clearing equilibrium in the labor markets, in a situation in which individual farms compete against each other for local farm labor."

The first and second suggestion are not followed here, precisely for the argument mentioned by Norton that labour supplies are not unlimited at the sub-regional level, certainly not in the circumstances of the Neguev. The third way makes use of an upward-sloping supply function of rural labour. In that way, the wage is also a variable of the model. By linearising this function, the linear programming model can establish the optimal value of both the quantity of labour and its wage. This might be tried, but would not be without complications as the exchange of labour between farms within the Neguev does not exactly constitute the same labour market as the market for labour from outside the Neguev. However, no data exist to postulate with any degree of confidence the required labour supply function. Therefore, no efforts regarding the third solution are made.

Here, an attempt will be made along the lines of the fourth alternative. For this purpose, new variables $L_{fm}$ are created, standing for the amount of outside labour hired by a particular farm type $f$ in a certain month $m$. The new variables are included in equations (6.13) and (6.14) to allow for hiring labour outside the Neguev. More precisely, equation (6.13) becomes equation (7.1).

$\sum_{f} H_{fm} - \sum_{f} O_{o=1,fn} - \sum_{f} L_{fm} \leq 0 \quad \text{all } m \quad (7.1)$

Equation (6.14) is changed into equation (7.2).

$H_{f,q,m} - \sum_{f \neq q} O_{o=1,fn} - L_{f,q,m} \leq 0 \quad \text{all } m, q=1,2,3,4,5 \quad (7.2)$

It should be clear that the hired labour variables $H_{fm}$ now have a different meaning than in the original model. They now stand for all hired labour, irrespective of whether it comes from other farm types within the Neguev or from outside the area. Lastly, a balance equation is made to calculate the sub-regional totals for hired labour from outside the Neguev in each month.

$\sum_{f} L_{fm} - L_{m} \leq 0 \quad \text{all } m \quad (7.3)$

In this way each farm type can hire labour from other farm types within the Neguev or from outside the Neguev. The objective function, corresponding to the economic surplus of all farm types, is not changed. Valuing of hired labour is still done via the wage $w_{m}$ of the hired labour variables $H_{m}$, implying that in this respect no distinction is made between the two types of hired labour. Starting from ₪ 110 per hour, the wage for hired labour (note 119, page 153) is increased in steps of ₪ 110 in those months in which the use of hired labour is higher than the labour available inside the Neguev. The process stops
An alternative formulation of the labour market when no more labour is hired from outside the area. The successive steps are shown in Table A.4.

When the current wage applies in all months, outside labour is hired in July, August, October and December. The quantities of hired labour in these months clearly exceed the use of labour available from within the Neguev. Taken over the year as a whole, the use of labour from outside is 95% of the use of labour from inside the Neguev.

The possibility for bringing in labour allows a completely different land use. This can be observed in Table A.5. Nearly all land is planted with cassava instead of palm heart as in the base scenario. This is an important outcome; within a given structure of land units and land use types, the costs and availabilities of factors of production other than land determine the use of land. In this case it concerns labour, but it also could apply to capital. Furthermore, the same would apply to other scarce factors or demand constraints. As Table A.5 shows, the economic surplus would be 54% higher than the surplus in the base scenario. In other words, at a wage of $110 per hour, hiring labour from outside the Neguev would substantially increase the economic surplus of the farms inside the Neguev. However, one must keep in mind that only a few outsiders would be willing to work inside the Neguev at this wage. In order to attract more labour from outside, wages should increase at least up to the level of plantation wages. To model the supply side of the labour market, a labour supply function should be incorporated. As was mentioned above, this is not possible at present due to a lack of appropriate data.

With regard to the demand for labour, the reader can follow for himself the consequences of successive wage increases with respect to outside labour use, land use, economic surplus and its distribution over the farm types. At a wage rate of $770 per hour in July, and wages from $220 to $660 in the remaining months, hardly any outside labour would be hired (Table A.4). With this wage structure land use approaches the pattern found in the base solution (Table A.5), with palm heart as the most important crop. The economic surplus is only 2% less than in the base scenario. However, the distribution of this surplus over the farm types is different (Table A.5). Farm types 1 and 5 would earn relatively more, farm types 2, 3 and 4 less. Although the differences in percentages are not large, differences in average surplus per farm can be considerable. Farm type 1 has a 2.6% larger surplus in the $770 hired labour alternative compared with the base scenario; farm type 5 gains only 0.7%. On the other hand, farm type 2 would lose 18.4%, farm type 3 would lose 2.1% and farm type 4 would lose 10.9%. Thus, by simulating competition between the farm types for scarce labour, creating a market clearing equilibrium for outside labour, the income distribution between the farm types comes more in line with the theoretical outcome of such a market.

However, there is a caveat. In the $770 hired labour alternative, as in the other hired labour alternatives, hired labour consists exclusively of outside labour. No use is made of hired labour from other farm types within the Neguev. Household labour not used for on-farm work, is working on plantations (paying $208.60 per hour), while at the same time labour is attracted from outside the Neguev. This is remarkable where wages for hired labour are higher than the plantation wage and is explained by the collective nature of the model. Irrespective of the cost for hired labour - which was assumed to be the same for labour from inside as for labour from outside the Neguev - for the area as a whole, an hour worked on other farms gives a return of $99, while one hour’s work on a plantation pays $208.60. As one hour hired labour is deducted from the objective function in both cases, the model opts for working on a plantation.

In order to address the above problem, the model is adapted again. Equations (6.13) and (6.14) are kept as they were in the original model. Now equation (6.9) is changed. It will contain the variables $L_{m}$ for hired labour from outside the Neguev by a particular farm type in a certain month. So equation (6.9) becomes equation (7.4).
The variables $H_{fm}$ again have their original significance: hired labour originating from other farm types within the Neguev. The objective function is also adapted. In equation (6.1), in addition to the deduction of the wage bill for hired labour from other farms within the Neguev ($\sum m w_{fm} H_{fm}$), hired labour from outside the Neguev is subtracted ($\sum m I_{fm} L_{fm}$), where $I_m$ is the wage for outside labour in month $m$. When the wages for ‘inside’ and ‘outside’ hired labour are equal, the solutions are exactly the same as those presented in Table A.4 and Table A.5. However, when ‘inside’ hired labour is offered at a ‘bargain’ rate (for example, at a wage $\not\equiv 110$ per hour less than that of ‘outside’ hired labour\(^{148}\)), it is preferred to ‘outside’ labour. It allows a slightly higher overall surplus at the expense of farm types 1 and 5, in favour of farm types 2, 3 and 4. Thus, by making ‘inside’ labour cheaper than ‘outside’ labour in this version of the model, it brings back one of the labour market features of the base scenario.

In conclusion, it is possible to simulate an aspect of the market for rural labour, namely the competition between farms for such labour. In that way farms maximise the surplus of their own farm instead of the collective surplus, at least with respect to labour use. This is reflected in a different surplus distribution between farm types. However, it was not possible to get rid of all ‘collective’ aspects of the model, because the supply side of the rural labour market has not (yet) been built into the model. This would be important, as the amount of labour available and willing to work on the farms is an important element in the determination of land use. The iterative procedure to increase the wages in successive steps is cumbersome. As the appropriate wages in each month have to be approached in successive steps, it is time-consuming and open to arbitrary choices.

\[ \sum_s \sum l \sum t c_{fm} x_{fm} - F_{fm} - H_{fm} - L_{fm} \leq 0 \quad \text{all } f, m \quad (7.4) \]

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\(^{148}\) Calculated in an adapted version of the ‘$\not\equiv 770$’ maximum hired wage alternative, in which the wages from January to December are 550, 220, 220, 220, 550, 220, 660, 440, 440, 550, 220, 440 (all wages in $\not\equiv$ per month).
**An alternative formulation of the labour market**

Table A.4 Use of labour from outside the Neguev, expressed as a percentage of the local labour use (per month and yearly total), in relation to monthly wages for hired labour

<table>
<thead>
<tr>
<th>Successive hired wage alternatives, indicated by the highest wage (Colones hour⁻¹) in a particular month</th>
</tr>
</thead>
<tbody>
<tr>
<td>month</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>January</td>
</tr>
<tr>
<td>February</td>
</tr>
<tr>
<td>March</td>
</tr>
<tr>
<td>April</td>
</tr>
<tr>
<td>May</td>
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<td>June</td>
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<tr>
<td>July</td>
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<td>August</td>
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<td>September</td>
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<tr>
<td>October</td>
</tr>
<tr>
<td>November</td>
</tr>
<tr>
<td>December</td>
</tr>
<tr>
<td>Year</td>
</tr>
</tbody>
</table>

1. Hired labour wages per month (Colones hour⁻¹)
2. Hired labour from outside the Neguev as a percentage of local labour use in a particular month and for the year as a total
3. - stands for zero
4. 0 stands for less than 0.5
Table A.5  Use of non-forest land, distribution of total economic surplus over farm types, and total economic surplus, in relation to monthly wages for hired labour

Successive hired wage alternatives, indicated by the highest wage (£ hour⁻¹) in a particular month

<table>
<thead>
<tr>
<th>LUST</th>
<th>110</th>
<th>220</th>
<th>330</th>
<th>440</th>
<th>550</th>
<th>660</th>
<th>770</th>
<th>base</th>
</tr>
</thead>
<tbody>
<tr>
<td>pasture with livestock on SFP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>202</td>
<td>238</td>
<td>350</td>
<td>350</td>
<td>-</td>
</tr>
<tr>
<td>cassava on SFP</td>
<td>-</td>
<td>-</td>
<td>131</td>
<td>221</td>
<td>184</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>palm heart¹ on SFW</td>
<td>-</td>
<td>-</td>
<td>638</td>
<td>761</td>
<td>761</td>
<td>730</td>
<td>530</td>
<td>732</td>
</tr>
<tr>
<td>tree plantation on SFW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>31</td>
<td>240</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>cassava on SFW</td>
<td>761</td>
<td>761</td>
<td>123</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>palm heart¹ on SUW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1134</td>
<td>1969</td>
<td>1945</td>
<td>1935</td>
<td>1944</td>
</tr>
<tr>
<td>palm heart² on SUW</td>
<td>86</td>
<td>86</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cassava on SUW</td>
<td>2111</td>
<td>2111</td>
<td>2197</td>
<td>1063</td>
<td>229</td>
<td>252</td>
<td>263</td>
<td>254</td>
</tr>
</tbody>
</table>

farm types (FT)

| FT1 (% of economic surplus)       | 7.11| 7.71| 8.14| 8.59| 8.63| 8.69| 8.71| 8.34 |
| FT2                              | 2.77| 2.59| 2.31| 2.06| 1.96| 1.87| 1.79| 2.16 |
| FT3                              | 15.31| 15.39| 14.99| 15.87| 15.83| 15.85| 15.86| 15.91|
| FT5                              | 60.44| 60.00| 60.79| 59.06| 59.45| 59.85| 60.01| 58.57|

| economic surplus (£ 10⁶)         | 642 | 551 | 481 | 420 | 414 | 411 | 410 | 418  |

¹ Palm heart using herbicides for weeding
² Palm heart using manual labour for weeding
Robert Alexander Schipper was born on 14 February 1949 in Bloemendaal, the Netherlands. In 1966, after obtaining the HBS-B diploma from the Kennemer Lyceum in Overveen, he started his studies at the Landbouwhogeschool in Wageningen. He began studying phyto-pathology, but soon it became clear that this would be the wrong track. He switched to Landhuishoudkunde van de Tropen en Sub-tropen (Agricultural economics of tropical and subtropical areas). He experienced his first tropical tastes and smells in Surinam during his praktijkijd in 1972. The main aim was, of course, to get some idea of the work of an agricultural economist, in this case by assisting with a multi-visit survey among vegetable producers. After this period, he made a year-long trip visiting development projects in Latin America, Australia and Indonesia. As the name and the content of the study in Wageningen changed, he obtained his ingenieurs diploma in economics in 1976, with a major in development economics, and minors in general economics, mathematical statistics and agricultural law.

His first job was with the International Agricultural Centre, Wageningen, as a member of the research group ‘The Small Farmer and Development Cooperation’. At the end of 1976 he left for Peru to join a team which studied the impact of a Dutch financed project to improve tobacco production in Tarapoto on farm incomes and employment.

In 1977 he joined FAO as an associate-expert. His first post was in Panama, working on a project for agricultural development planning. This job gave him the opportunity to immerse himself in agricultural planning and policy issues. His second assignment with FAO was in Rome. From mid 1979 until the end of 1980 he worked for the Farm Management and Production Economics Service, helping with the development of a package for analysing farm surveys. Furthermore, at the request of the World Food Programme, he assisted with the organisation and analysis of a survey among settlers in the Terai, Nepal.

By the end of 1980 he joined Wageningen Agricultural University to work in Sri Lanka on a project of the Department of Development Economics. In collaboration with the Agrarian Research and Training Institute (ARTI), Colombo, the project studied questions concerning regional agricultural planning.

In 1982 the author returned to Wageningen to become a staff member of the Department of Development Economics. His research concerned economic aspects of land use and sustainability. Since then he has been based in Wageningen, but has also completed overseas missions to Kenya and Ethiopia. Since 1986 he has been to Costa Rica numerous times, as a regular visitor to the Atlantic Zone Programme, a collaboration between the Wageningen Agricultural University and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Ministerio de Agricultura y Ganadería and the Universidad Nacional, all three in Costa Rica.

At present, the author continues to work for the Wageningen Agricultural University. His research efforts concern issues related to sustainable resource use in agriculture. He teaches courses in ‘Regional agricultural development: analysis and policy’ and ‘Natural resources and land use in developing countries’, and shares teaching in ‘Cost benefit analysis’ and ‘Farm management research’.
Figure 7.1: Maps of land use in the Neguev. A: base scenario and 50% reduction variant of palm heart price.